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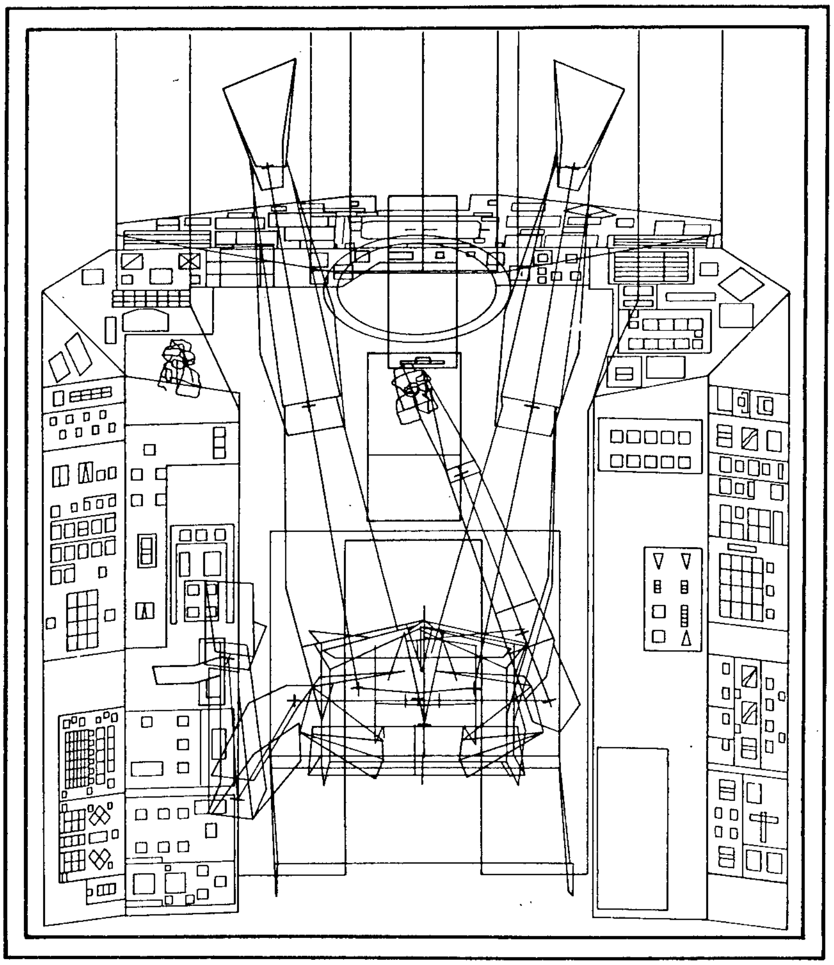

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COCKPIT GEOMETRY EVALUATION

PHASE I FINAL REPORT
VOLUME III–COMPUTER PROGRAM

JANUARY 1969

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VOLUME	DOCUMENT NUMBER	TITLE
I	D162-10125-1	PROGRAM DESCRIPTION AND SUMMARY
II	D162-10126-1	HUMAN DATA
III	D162-10127-1	COMPUTER PROGRAM
IV	D162-10128-1	MATHEMATICAL MODEL
V	D162-10129-1	VALIDATION

COCKPIT GEOMETRY EVALUATION

PHASE I

FINAL REPORT

VOLUME III–COMPUTER PROGRAM

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FOREWORD

This report presents work which was performed under the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program, a research and exploratory development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Electronics Command, the Naval Air Systems Command, and the Office of Naval Research through an organization known as the JANAIR Working Group. The Working Group is currently composed of representatives from the following offices:

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ABSTRACT

A computer program for the evaluation of cockpit configurations using a 23-pin-joint articulated stick-man (BOEMAN-I) is presented. The program utilizes an updatable bank of anthropological and environmental data, and simulates the motion of a real pilot performing tasks in a crewstation. The program provides information concerning reach capability, locations and orientations of joints, pilot-cockpit visual interferences, numerical performance indicators on joint displacement and deflection, and mass displacements. The program provides also a statistical validation when comparing real pilot and BOEMAN-I paths of motion.

KEYWORD LIST

Anthropometry
Cockpit
Design
Environment
Geometry
Human Engineering
Interference
Line of Sight
Non-Linear Optimization
Motion
Performance
Simulation
System
Task
Visual
Workload

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1.0 INTRODUCTION

1.1 PROJECT DESCRIPTION

The Cockpit Geometry Evaluation (CGE) Methods Project is an experimental study funded by the Joint Army Navy Aircraft Instrumentation Research (JANAIR) committee to develop an objective method of evaluating the physical compatibility of crewmen with specified workstations. The first phase of this project includes the development of a Computer Program System, called BOEMAN-I. This program serves as the basic tool to store required anthropological and geometric data, make computations, and conduct evaluations of typical crew movements during performance of tasks in a specific crewstation configuration (geometry). BOEMAN-I is also the name given to the 23-pin-joint man-model upon which the system is based.

This volume of the Phase I Final Report discusses the BOEMAN-I Computer Program System.

1.2 COMPUTER PROGRAM REQUIREMENTS AND ASSUMPTIONS

The BOEMAN-I Computer Program System is a sequential set of FORTRAN IV programs for the CDC 6600 that provide the capability to (1) store large and varied amounts of data, (2) retrieve selected subsets of data, (3) calculate human body joint locations, (4) calculate selected numerical performance indicators (based on (3)), and (5) validate BOEMAN's paths of motion compared with those of real pilots. These capabilities are an outgrowth of the requirements placed on the program at the beginning of Phase I as well as various assumptions made in order that an operational evaluation tool would result.

REQUIREMENTS

The BOEMAN-I Computer Program System is designed and developed primarily to meet seven requirements for the Cockpit Geometry Evaluation study. These requirements may be categorized as follows: development of a cockpit evaluation tool, and the testing of the Phase I computer program.

(1) To establish a common reference system to evaluate the physical compatibility of an operator/crewstation layout. In the program, two reference systems are used. The first is a Euclidean coordinate system whose origin is at the cockpit eye reference point. Data on cockpit geometry plane vertices and control locations are expressed in this reference system initially. The second is a Euclidean coordinate system whose origin is at the lumbar joint, and such that when BOEMAN-I is initially seated in the cockpit, his eye midpoint is at the cockpit eye reference point. The program transforms all data from the first system to the second at the beginning of an evaluation run. These coordinate systems are necessary because the lumbar joint location is dependent upon BOEMAN-I's link dimensions.

(2) To produce repeatable crewstation evaluation results regardless of the investigator. Repeatable results depend on: universal availability of and well-defined procedures for generating the anthropological, geometric and flight mission data; consistent application of the model in regard to step size during a task sequence, error bounds, weighting coefficients, and preferred angles (all of these relating to the objective function of

and the entire optimization procedure); relative insensitivity of the model to differing initial conditions brought about by utilizing different computers.

(3) To permit crewstation evaluations to be accurately performed using an acceptable amount of time and expense. For Phase I, hand joints with respect to the control locations are calculated with tolerance limits of one inch. Currently, on the basis of CDC 6600 computer time required to process a flight mission of seven tasks, joint position calculations (up to 15 positions per task) require between 3 and 4 minutes per task. However, this can be reduced significantly by decreasing the number of intermediate positions required in tasks of relatively small distance.

(4) To permit specific items that interfere with crew movement to be identified and indicate areas where improvement is most beneficial. The program uses bounded cockpit planes and tests each of them for the occurrence of visual interference with BOEMAN's line of sight. If interference occurs, a correction procedure is used to move BOEMAN-I as required to avoid the blocking plane. Physical interference of BOEMAN-I's links with the seatback is also identified but currently no correction is applied.

(5) To permit the evaluator to consider dynamic motion with real time effects, variations in operator size, simple and complex action and physical restraints. The BOEMAN-I system utilizes task data that simulates the duration of a human motion and the generated positions correspond to this time interval. The task sequence used in the sample input (Section 3.5) requires that the operator begin with his hands on the control stick. He then responds to a failure of the hydraulic system by resetting the master caution button, operating the utility power control, and then he resumes the initial position.

The individual link percentiles are user specified, providing for size variations of the operator. Physical restraints such as lap belts or shoulder harnesses are provided for by restrictions on the angular limits of pertinent joints.

(6) To produce results in a form applicable to either program management or design development decisions. The program produces a printed history of the flight mission or task sequence for evaluation. There are user-controlled options available to vary the size and content of the output depending on the purpose of the evaluation. The options include

suppression of any or all input data, and expansion of the processing and summation sections. The system automatically provides for a minimum of printout when a task is performed feasibly. Section 3.1 contains the user input options; Section 3.5 contains a sample printout of all input data and the processing and summation data for one task.

(7) To provide a method for validation of the mathematical model of human motion. The BOEMAN-I program system contains a statistical program used in the validation during Phase I. It is discussed in Section 2.1.3 of this document; comparison of BOEMAN-I and human paths of motion is discussion in the Validation Document (Volume V, D6-53620-3).

ASSUMPTIONS

The computerized model utilizes five operational assumptions:

(1) Each of BOEMAN-I's hands (palm joints) moves in a straight line during the task (provided there is no blocking object between the initial and final positions).

(2) BOEMAN-I's upper torso is movable whereas his lumbar joint, hips and legs are fixed in a seated position.

(3) Joint angular constraint limits are not part of the optimization procedure, although violations are identified for an infeasible task.

(4) Correction for visual interference is made assuming only one interfering cockpit plane.

(5) BOEMAN-I's movement during a task neglects the effects of acceleration, deceleration, and gravitational forces as well as familiarity with any given crewstation.

The remainder of this document contains a discussion of the programs in the BOEMAN-I system, a user's guide and a set of appendices detailing program subroutines, definitions, block common and control code names.

1.3 RESULTS

The computer program system developed for the Cockpit Geometry Evaluation Methods Program has the capability of positioning a 23-joint, articulated stick-man (BOEMAN-I), with variable sized link dimensions. The baseline model performs portions of a flight mission (task sequence) in a given cockpit configuration. For each mission task, numerical performance indicators are calculated and visual interference is detected and eliminated. The capability of storing and retrieving anthropological, geometric, and flight mission data is built into the program. In addition, a validation program compares BOEMAN-I's paths of motion with those of real pilots.

Successful running of the BOEMAN-I Computer Program System has been accomplished and validations performed against human movement criteria.

1.4 CONCLUSIONS

The BOEMAN-I Computer Program System demonstrates that applying a computerized human motion model to a crewstation environment is feasible. Its ability to generate relatively smooth, continuous and stable joint paths of motion, test for visual and physical seatback interference, and calculate numerical performance indicators provide a first step toward evaluating the overall physical utility of a workstation design.

1.5 RECOMMENDATIONS

(1) The present program should be refined to minimize core storage. This would reduce the problem of conversion to computers other than the CDC 6600.

(2) The program should be made more efficient in terms of both program logic and mathematical techniques used. These revisions would reduce the machine time needed to calculate joint positions.

(3) A study should be made to determine the feasibility of performing an interference analysis during joint position calculations rather than after such calculations. This would provide corrections to the paths of motion while being generated.

(4) Card input data (supplied by the user) should be reduced and made more compact to prevent non-execution runs due to card input errors.

(5) The output format of the program should be revised to provide complete flexibility, allowing the user to specify content and format of the output.

2.0 PROGRAM DESIGN

2.1 GENERAL

The set of three program groups - Storage and Retrieval, Cockpit Geometry Evaluation (CGE), and Validation - is called the BOEMAN-I Computer Program System. The Storage and Retrieval programs provide an input stream to the CGE. The Cockpit Geometry Evaluation's functions include accepting and transforming user input, synthesizing joint locations, identifying interference, providing output for the user, and generating an input stream for the Validation. Validation compares man-made and computer-generated paths of motion; therefore, it requires a separate stream for the experimentally determined data. Each of the groups (except the storage program), therefore, must be run sequentially since they are each dependent upon previously generated data tapes. The activity flow is shown in Figure 1.

The Computer Program System provides a data bank of information relating to the workstation, the crew, and the flight mission to be performed. Data on the workstation consists of vertices of identified cockpit planes, and a table referencing coded names and locations of controls in the cockpit (See Appendix VIII). Crew data include a survey of size, mass, and centroids of links stored as means, standard deviations, and a table of normal deviates. In addition, angular limits of joints and a standard angular orientation are stored.

Flight mission data consist of the successive controls to be reached, and viewed, corresponding hand orientations, and time values for reaching and holding controls. (See Section 3.5 for a listing of the data bank contents used in Phase I.) Hence the flight mission is a sequence of tasks. A

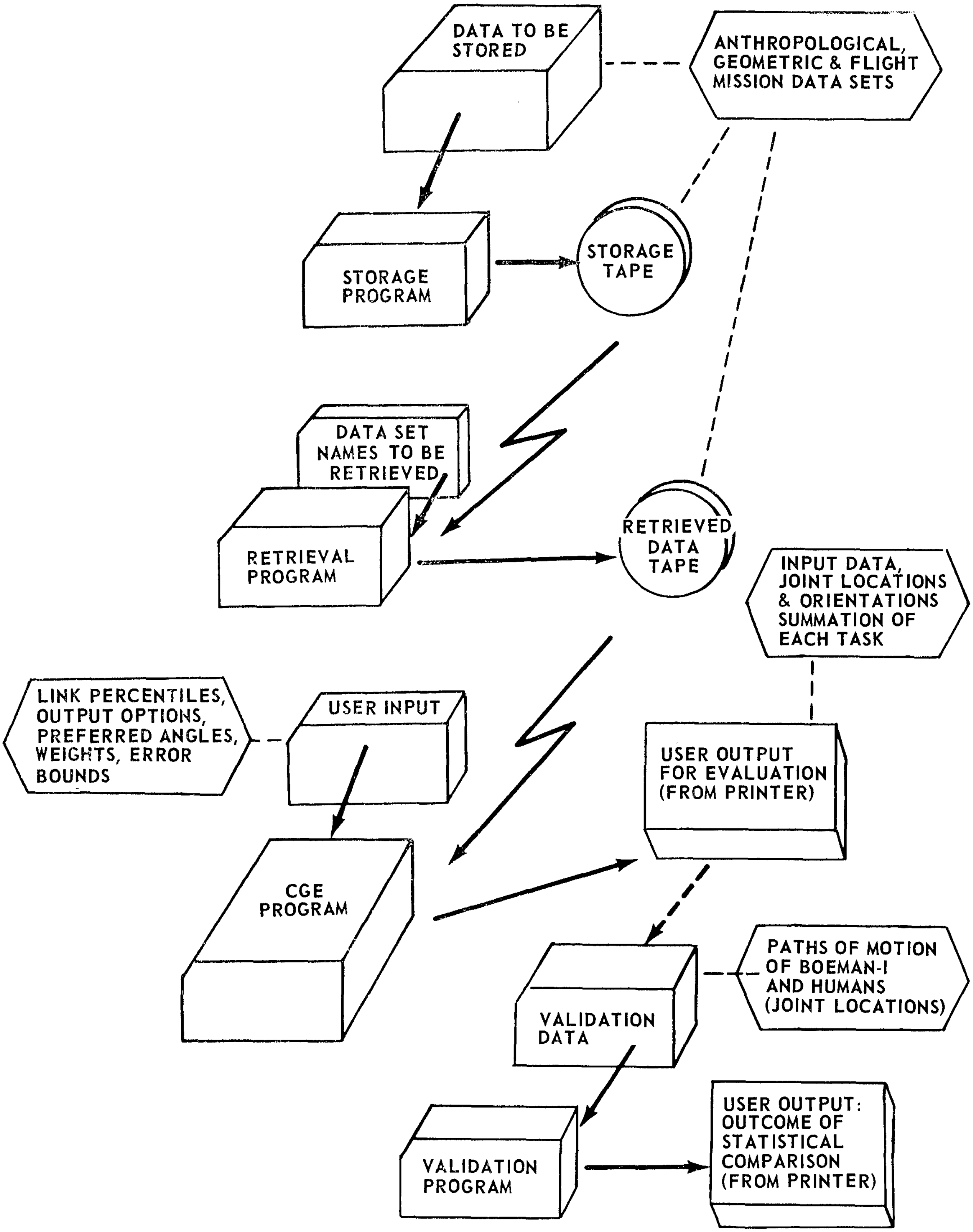

DATA TO BE STORED
ANTHROPOLOGICAL, GEOMETRIC & FLIGHT MISSION DATA SETS
STORAGE PROGRAM
STORAGE TAPE
DATA SET NAMES TO BE RETRIEVED
RETRIEVAL PROGRAM
RETRIEVED DATA TAPE
INPUT DATA, JOINT LOCATIONS & ORIENTATIONS SUMMATION OF EACH TASK
LINK PERCENTILES, OUTPUT OPTIONS, PREFERRED ANGLES, WEIGHTS, ERROR BOUNDS
USER INPUT
USER OUTPUT FOR EVALUATION (FROM PRINTER)
CGE PROGRAM
PATHS OF MOTION OF BOEMAN-I AND HUMANS (JOINT LOCATIONS)
VALIDATION DATA
VALIDATION PROGRAM
USER OUTPUT: OUTCOME OF STATISTICAL COMPARISON (FROM PRINTER)

Figure 1. Data Flow Diagram

task is defined as a movement of BOEMAN-I's hand link from an initial position to a final position and/or the viewing of a specified control.

The storage program allows the user to generate on magnetic tape his own evaluation data or to add data to the existing data bank. The retrieval program allows selection of data sets from the data bank. Both of these programs are described in Sections 2.1.1, 3.1, and Appendix V. A more general description of usage may be found in Reference 13.

BOEMAN-I is required to perform a task sequence in a given cockpit configuration. Each hand must be on some control and a specific cockpit location is being viewed when the task is completed. The task is subdivided into steps, where each step is defined as that position which corresponds to an interval on a straight line path for each hand joint. For each task, paths of motion are formed based on the successive calculation of the locations and orientations of BOEMAN-I's joints.

As BOEMAN-I begins a task, it is necessary to determine whether the controls to be actuated are within reach. If they are not, the given task is deemed infeasible and is redefined to reflect the closest distance to the original task that may be feasibly reached.

Interference occurs if a control cannot be viewed or if any links intersect with the seatback.

The calculation of joint locations and orientations, discussions of reach feasibility (reach analysis), and resulting BOEMAN-workstation geometry interactions (interference analysis) may be found in Volume IV, Mathematical Model (D6-53620-2), Sections 3.2 through 3.4.

The numerical performance indicators of the evaluation include: (1) individual task as well as cumulative task displacement of joint and mass centroid locations, (2) work done during each task and the entire task sequence, (3) joint angular deflections per task and task sequence (using only twist), and (4) head and eye deflections per task and task sequence (using full rotational capability). The calculations are detailed in Section 2.2.5, Summation Overlay.

Validation consists of a statistical procedure for comparing the paths of motion generated by BOEMAN-I with corresponding (experimentally determined) paths of motions of humans. By use of an F-test, the hypothesis that BOEMAN-I paths do not significantly differ from those of humans is examined.

2.1.1 Storage and Retrieval

The storage program creates a data bank of information used by the BOEMAN-I system. The bank includes data such as anthropometric and physical characteristics of a human population and is stored on magnetic tape for later use. The bank is partitioned into data sets, each of which contains a category of anthropometric data such as joint angular excursion limits (or a particular version of a category, such as link dimensions and mass quantities). The data sets must be an acceptable format for the input transformation overlay of the evaluation program*. In creating the bank, data set identification labels are supplied by the user and are utilized in the retrieval program. In addition, the user must specify the number of data sets to be stored and provide delimiters between data sets.

*Data sets in some alternate form (or order) would require appropriate modification of the input transformation overlay.

The retrieval program allows for selective retrieval of one or more of the data sets using the appropriate identification labels. The retrieval data is also stored on magnetic tape and serves as a basis for the particular evaluation "run". A restriction on the retrieval program is that the order of the retrieved data sets must agree with the order required by the input transformation overlay*. The usage of the storage and retrieval programs may be found in Section 3.0. A list of subroutine names is given in Appendix V. Both of these programs were derived from a standard Boeing package for use in the BOEMAN-I Computer Program System.

2.1.2 Cockpit Geometry Evaluation

The Cockpit Geometry Evaluation Computer Program consists of six overlays, each having a specific function within the evaluation. These overlays are:

(1)	INTRAN	(Input Transformation)
(2)	REACHA	(Reach Analysis)
(3)	MAN1	(Baseline Man-model)
(4)	INTERF	(Interference Analysis)
(5)	SUMM	(Summation)
(6)	OUTGO	(Output)

The CGE program provides joint locations and orientations of BOEMAN-I as well as numerical indicators summarizing information about the path generated in performing a task in a cockpit configuration. To reduce storage requirements and provide separation of function, the computer program is designed in overlay form with the above programs as primary

*Data sets in some alternate form (or order) would require appropriate modification of the input transformation overlay.

overlays and with a driver program as the main overlay. The main overlay directs calls to the primaries, and communicates data to them by means of Block Common. A flow diagram for the main overlay is given in Figure 2.

Subroutine POOL is a system routine which allows a collection of files, communicating with central memory solely via binary type read/write statements, to share a single common buffer. This also yields a substantial saving in core storage.

The variables set up in the main overlay (Block Common) are called global variables as they serve the same function (or one function at a time) throughout each overlay. The variables defined in each overlay are called local variables.

The purpose or function of each subroutine in the CGE program along with the input variables necessary for the subroutine and variables calculated are given in Appendix VI. The subroutines are arranged by overlay and according to when they are first encountered in the program. Appendix X gives an index of subroutine names and page references for their description.

A list of variables belonging to Block Common statements may be found in Appendix III. These account for input/output variables when a subroutine argument list is not used.

2.1.3 Validation

The validation program tests the hypothesis that the paths of motion generated by the BOEMAN-I system and the mean motions of a like-sized individual performing the same tasks are not significantly different. The

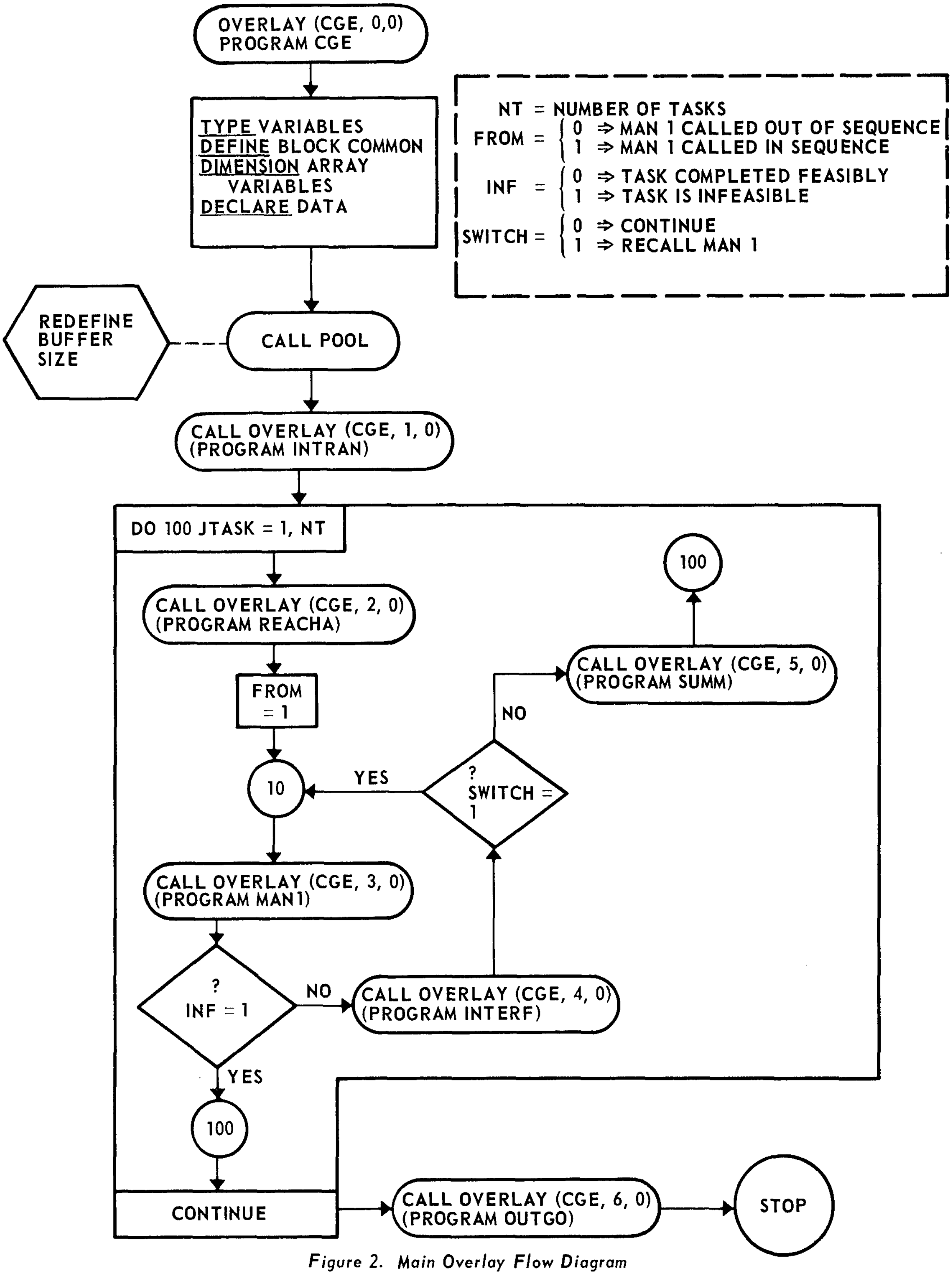


Figure 2. Main Overlay Flow Diagram

statistical procedure used to test this hypothesis involves computing an F-value that indicates whether the hypothesis should be accepted or rejected.

Thus, the input stream includes both BOEMAN's path and repeated motions of a corresponding individual during a task. The program calculates the individual's mean path and generates and inverts a covariance matrix from both paths. The result allows for the calculation of the F-value.

If the generated covariance matrix is singular, then an inverse cannot be found and no F-value can be calculated. Singularity is a function of the data used and if it exists, cannot be circumvented.

The method of the validation program is described in the validation document (Volume V). The usage of the program is contained in Section 3.0 and subroutine descriptions are presented in Appendix VII.

2.2 COCKPIT GEOMETRY EVALUATION OVERLAYS

2.2.1 Input Transformation Overlay

The purpose of Program INTRAN (OVERLAY, (CGE, 1, 0)) is to read data from the retrieval tape and user-specified punched cards. As each data set is read, it is transformed as required by MAN1 and other overlays. All input data and other variables calculated by INTRAN are written onto an intermediate file for use by the output overlay. The INTRAN overlay is called only once, handles all input to CGE, and contributes to the initial output using the intermediate file.

The program reads tape handling parameters and control options set by the user, for amount of output and an indication of whether a non-standard link dimension and mass (user defined) survey is being used. With these initialized, the link and mass data are read from the retrieval tape and with both the card input percentiles for each link and a normal distribution table (on tape), the percentiles are transformed into link lengths and masses. Task sequence information and joint angular limits are read. The angles are converted to radians. Upon completion of this, SUBROUTINE ANGLET is called upon to calculate the standard joint locations and initialize variables for the MAN1 overlay. Data describing the cockpit control codes and location of planes (with respect to the cockpit eye reference point) are then read. These and all of the data specifying "position" are transformed into locations with respect to the lumbar joint, which is dependent upon the calculated link size. Finally, the control locations specified by the task sequence are selected from the cockpit codes and stored. A list of subroutines local to this overlay may be found in Appendix I. A flow diagram for the INTRAN program is shown in Figure 3. A more detailed discussion of this overlay's subroutines may be found in Appendix VI and in user's guide (Section 4.0).

2.2.2 Reach Analysis Overlay

For each task, the reach analysis overlay determines if the control locations for each hand are within the specified sized BOEMAN's reach. If not, the control locations are repositioned to put BOEMAN within the reach envelope. This change is noted on the intermediate output file. Evaluation then proceeds with the new task based on the redefined control locations.

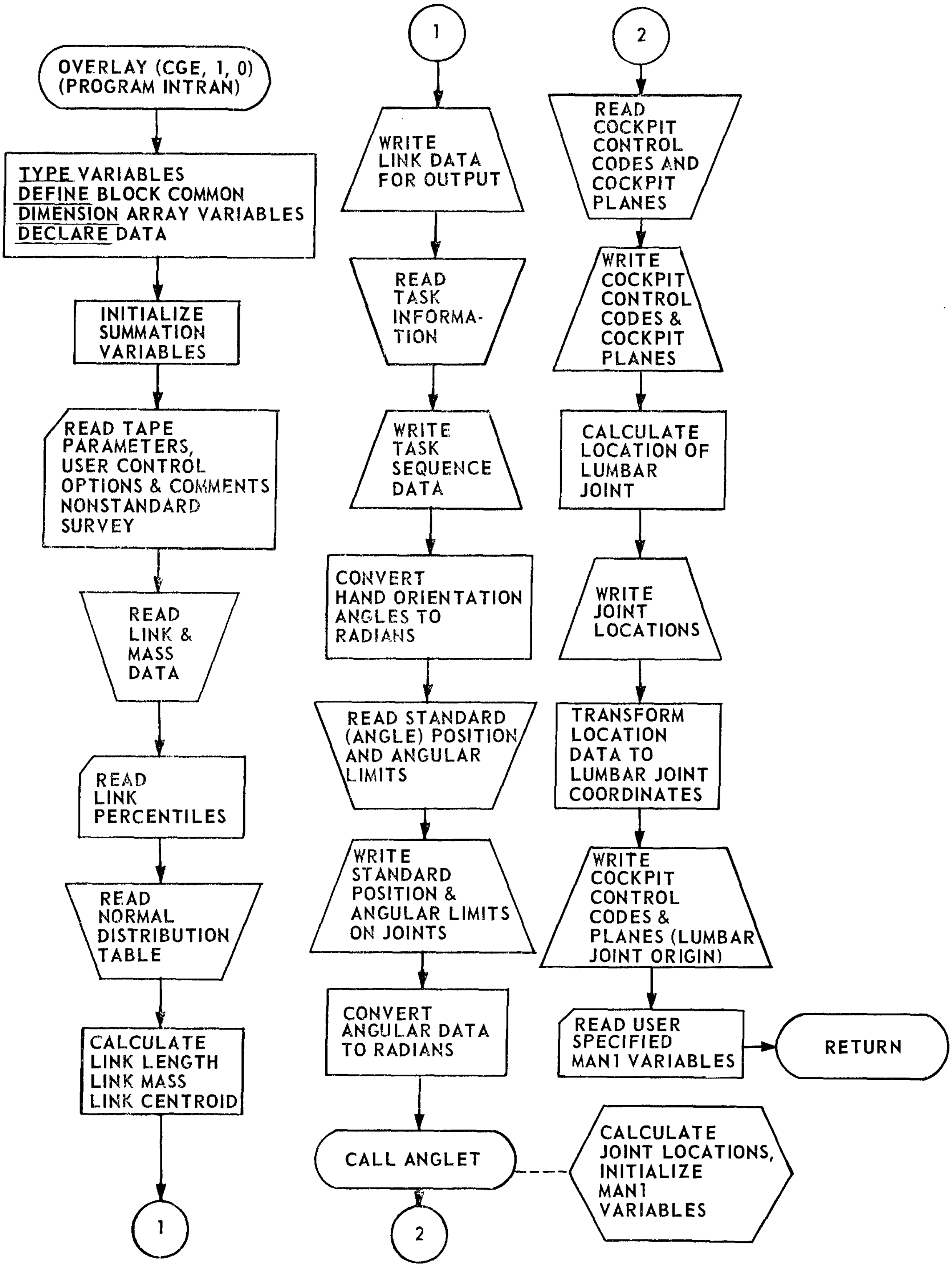

OVERLAY (CGE, 1, 0)
(PROGRAM INTRAN)
TYPE VARIABLES
DEFINE BLOCK COMMON
DIMENSION ARRAY VARIABLES
DECLARE DATA
INITIALIZE SUMMATION VARIABLES
READ TAPE PARAMETERS, USER CONTROL OPTIONS & COMMENTS NONSTANDARD SURVEY
READ LINK & MASS DATA
READ LINK PERCENTILES
READ NORMAL DISTRIBUTION TABLE
CALCULATE LINK LENGTH LINK MASS LINK CENTROID
1
1
WRITE LINK DATA FOR OUTPUT
READ TASK INFORMATION
WRITE TASK SEQUENCE DATA
CONVERT HAND ORIENTATION ANGLES TO RADIANS
READ STANDARD (ANGLE) POSITION AND ANGULAR LIMITS
WRITE STANDARD POSITION & ANGULAR LIMITS ON JOINTS
CONVERT ANGULAR DATA TO RADIANS
CALL ANGLET
2
CALCULATE JOINT LOCATIONS, INITIALIZE MAN1 VARIABLES
2
READ COCKPIT CONTROL CODES AND COCKPIT PLANES
WRITE COCKPIT CONTROL CODES & COCKPIT PLANES
CALCULATE LOCATION OF LUMBAR JOINT
WRITE JOINT LOCATIONS
TRANSFORM LOCATION DATA TO LUMBAR JOINT COORDINATES
WRITE COCKPIT CONTROL CODES & PLANES (LUMBAR JOINT ORIGIN)
READ USER SPECIFIED MAN1 VARIABLES
RETURN

Figure 3. Program INTRAN–Input Transformation Overlay

The input required for this overlay includes link lengths, current top of spine location, joint angular limits for the spine, and current task information. Using this, a top of spine position is calculated for the given task based on the discussion in the Mathematical Model Document (Volume IV, Section 3.2) and utilizing an optimization routine called MINUM.

MINUM determines the minimum value of a function of several parameters. (See Appendix IX for a description of MINUM.) If the task is infeasible, a new task is defined and the distance between old and new hand locations is calculated. This information along with the top of spine position is saved for the output overlay on the intermediate file. A flow diagram for program REACHA is given in Figure 4.

2.2.3 Baseline Man-Model Overlay

The baseline man-model overlay is concerned with the generation of BOEMAN's joint locations and orientations at specified intervals during the performance of a task. For this, link lengths, task time, terminal joint location and orientation, joint angular limits and the initial task position are required as input. These data, along with data read from cards in the input transformation overlay are used in the optimization routine LYNX, which determines joint angular values. LYNX uses an iterative process to determine the joint angles corresponding to a minimized objective function. This is done for each step of the task. If the process does not converge (i.e., a minimum is not realized), then it is assumed that some constraints are violated, and the amount of the violation is measured. A discussion of the objective function and the optimization

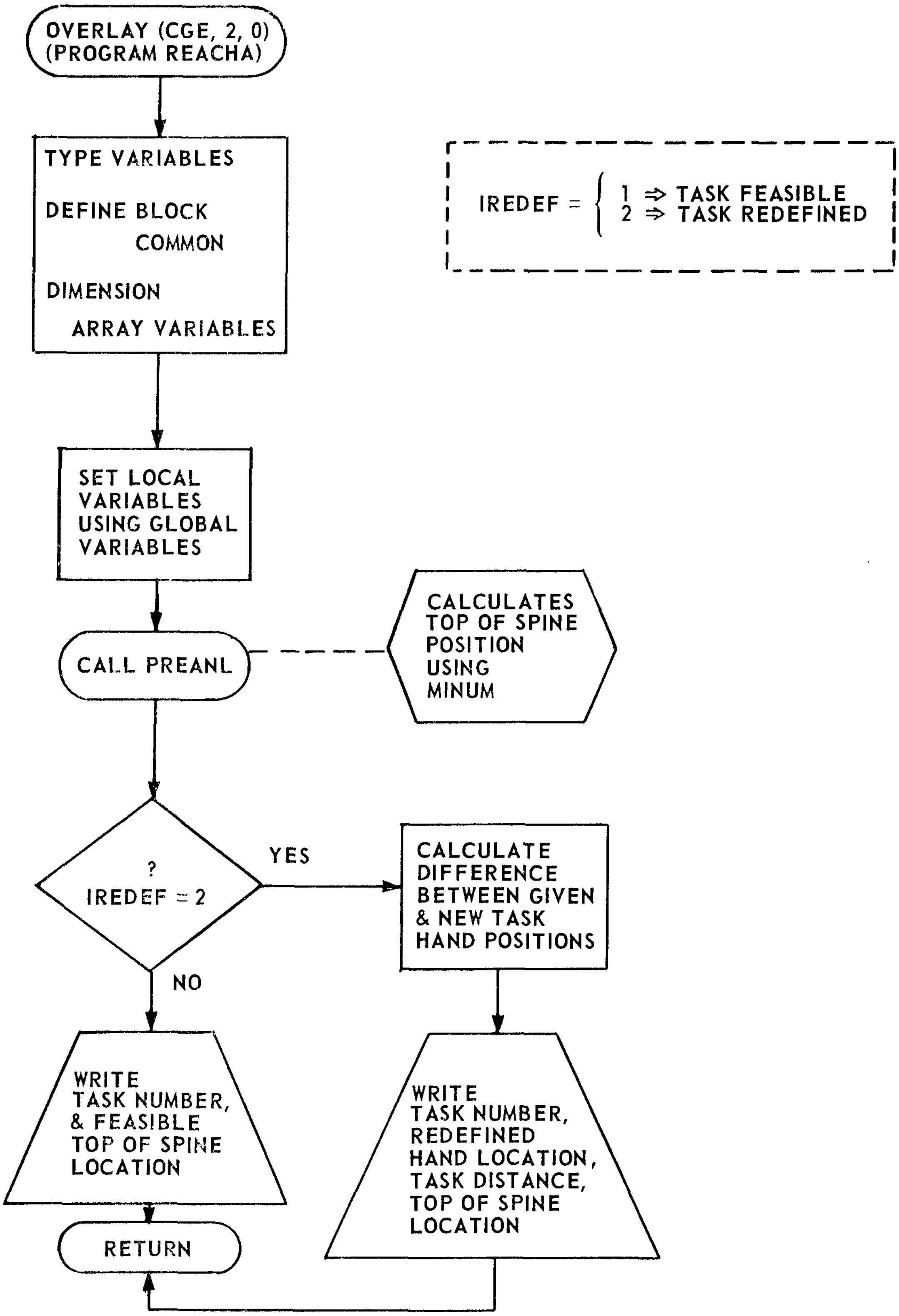

OVERLAY (CGE, 2, 0)
(PROGRAM REACHA)
TYPE VARIABLES
DEFINE BLOCK
COMMON
DIMENSION
ARRAY VARIABLES
IREDEF = { 1 ⇒ TASK FEASIBLE
2 ⇒ TASK REDEFINED
SET LOCAL VARIABLES USING GLOBAL VARIABLES
CALL PREANL
CALCULATES TOP OF SPINE POSITION USING MINUM
?
IREDEF = 2
YES
NO
CALCULATE DIFFERENCE BETWEEN GIVEN & NEW TASK HAND POSITIONS
WRITE TASK NUMBER, & FEASIBLE TOP OF SPINE LOCATION
WRITE TASK NUMBER, REDEFINED HAND LOCATION, TASK DISTANCE, TOP OF SPINE LOCATION
RETURN

Figure 4. Reach Analysis Overlay–Program REACHA

technique may be found in Section 3.3, Mathematical Model Document (D6-53620-2).

Program MAN1 is designed to generate supplementary output concerning variables of the optimization algorithm, if there is an infeasibility condition present. These variables are printed out in a separate section for later analysis. Output for the evaluation consists of joint angle values and joint positions at each step of the task and, for an infeasibility condition, those joint angles exceeding their limits, and the distance of each palm from its preset location. A flow diagram for Program MAN1 is presented in Figure 5.

2.2.4 Interference Analysis Overlay

Once a set of joint locations has been generated at the end of a task, the task is further scrutinized to determine if BOEMAN's position interacts visually or physically with the cockpit. If visual interference occurs, a correction procedure describing a new and uninterrupted line of sight is utilized. The correction procedure is not iterative. The testing of seatback interference occurs when the visual tests are completed. A discussion of the interference analysis may be found in Section 3.4 of the Mathematical Model Document (D6-53620-2).

Program INTERF (the interference analysis overlay) requires, as input, the task data, the location of the eye aiming point, the vertices of each plane comprising the cockpit geometry, the link lengths, and the calculated joint locations during and at the end of the task. These data are stored as local variables. The program first tests each plane for intersection with the line of sight. If visual interference occurs, the offending

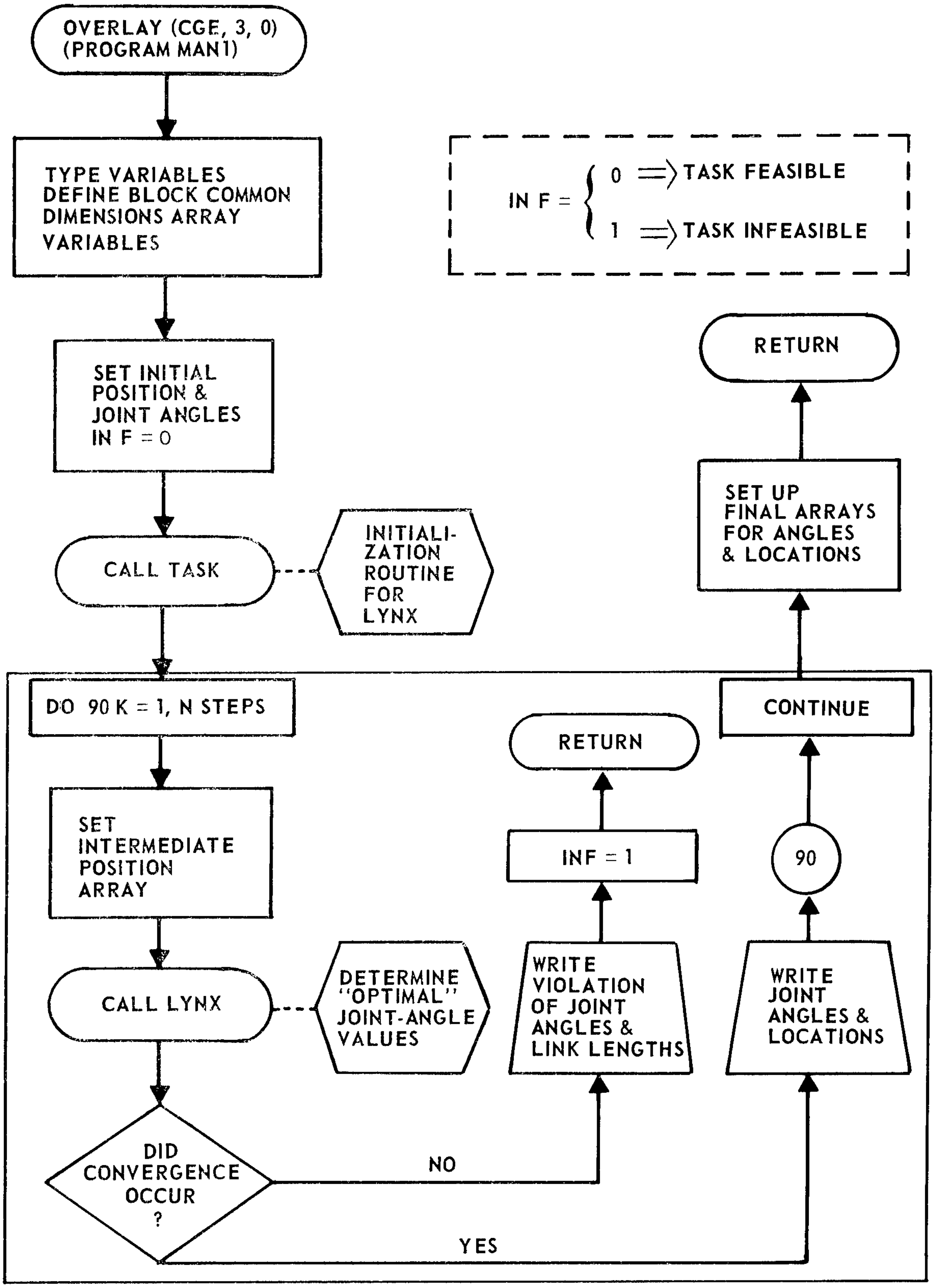

OVERLAY (CGE, 3, 0)
(PROGRAM MAN1)
TYPE VARIABLES
DEFINE BLOCK COMMON
DIMENSIONS ARRAY
VARIABLES
IN F = { 0 ⟹ TASK FEASIBLE
1 ⟹ TASK INFEASIBLE
SET INITIAL POSITION & JOINT ANGLES IN F = 0
CALL TASK
INITIALIZATION ROUTINE FOR LYNX
RETURN
SET UP FINAL ARRAYS FOR ANGLES & LOCATIONS
DO 90 K = 1, N STEPS
CONTINUE
RETURN
SET INTERMEDIATE POSITION ARRAY
INF = 1
90
CALL LYNX
DETERMINE "OPTIMAL" JOINT-ANGLE VALUES
WRITE VIOLATION OF JOINT ANGLES & LINK LENGTHS
WRITE JOINT ANGLES & LOCATIONS
DID CONVERGENCE OCCUR ?
NO
YES

Figure 5. Baseline Man-Model Overlay–Program MAN 1

planes with each intersection point are written on the intermediate output file. Similar tests are performed during each step of the task for physical interference with the seatback. All links on BOEMAN-I which intersect the seatback are also written on the output file but no correction for this physical interference is made in the Phase I model. If no interference occurs for the task, no output is generated by the Interference overlay. A general flow diagram for Program INTERF is given in Figure 6.

2.2.5 Summation Overlay

For successfully completed tasks, it is necessary to calculate numerical performance indicators describing BOEMAN's relative change in position and orientation. Several quantities have been selected as representative of his performance for comparative analysis within the task sequence and/or with similar tasks in other cockpits. Each quantity is calculated for each task and cumulatively for the specified task sequence. The performance indicators used are:

(1) Joint displacements for each joint

(2) Centroid displacements for each link

(3) Products of link mass and centroid displacement (work) for each link

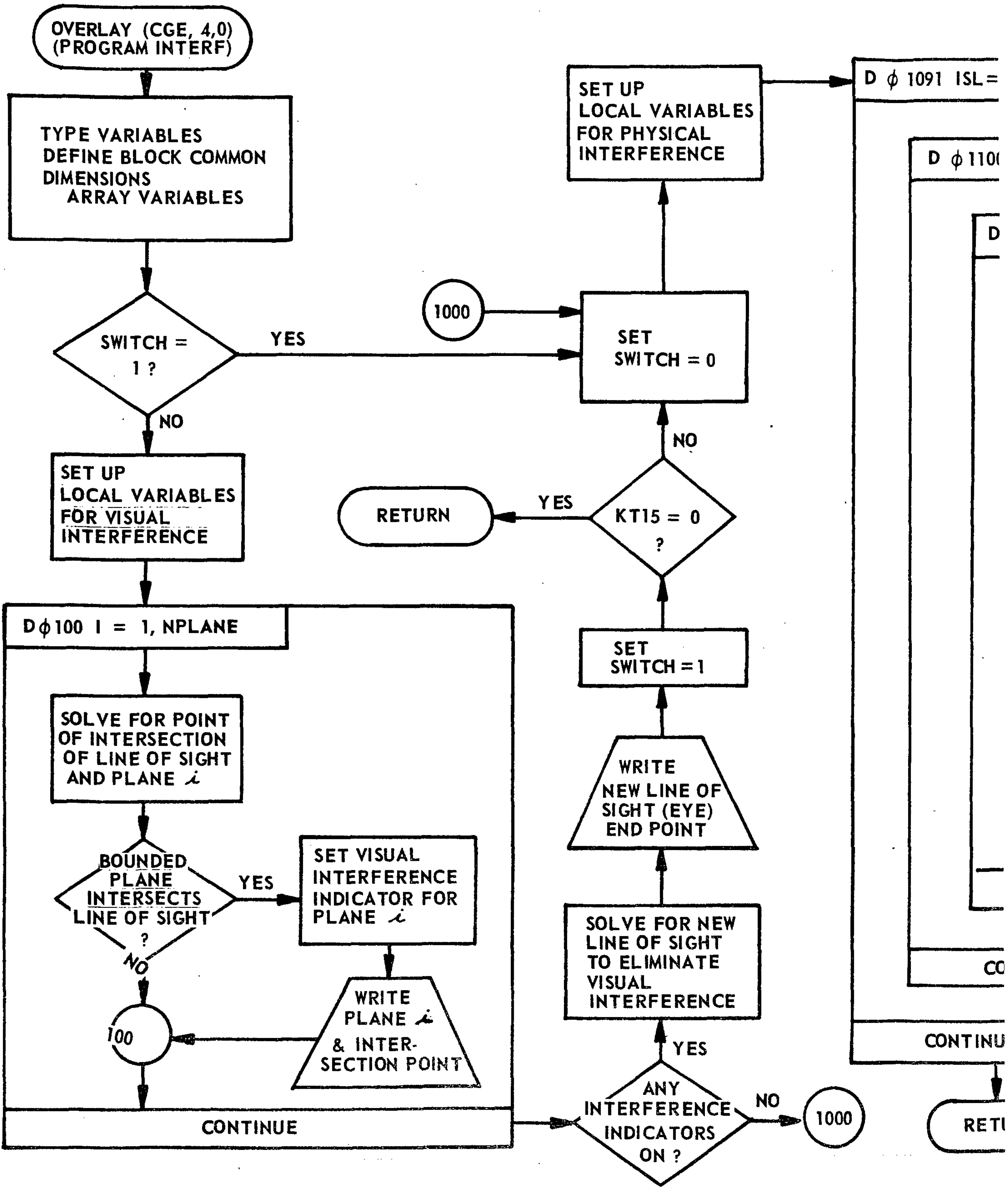
(4) Joint angular rotations (twist) for each joint

(5) Head deflection

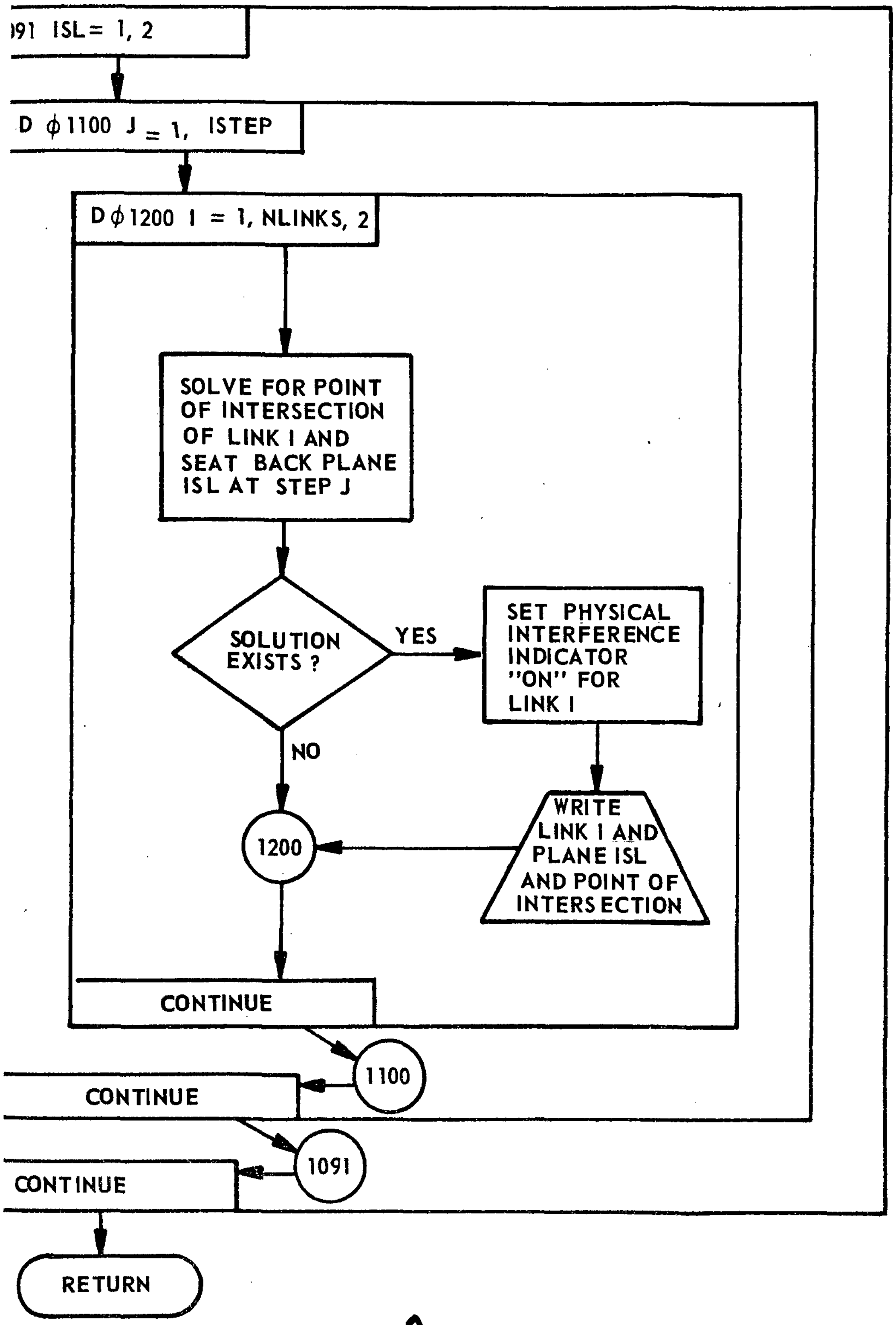
(6) Eye deflection

The input required for these computations includes initial and final joint locations during a task, centroid percentiles and mass on each link, task control locations, and initial joint angular and positional

VISUAL INTERFERENCE


OVERLAY (CGE, 4,0)
(PROGRAM INTERF)
TYPE VARIABLES
DEFINE BLOCK COMMON
DIMENSIONS
ARRAY VARIABLES
SWITCH = 1 ?
YES
NO
SET UP LOCAL VARIABLES FOR VISUAL INTERFERENCE
Dϕ100 I = 1, NPLANE
SOLVE FOR POINT OF INTERSECTION OF LINE OF SIGHT AND PLANE i
BOUNDED PLANE INTERSECTS LINE OF SIGHT ?
YES
NO
SET VISUAL INTERFERENCE INDICATOR FOR PLANE i
WRITE PLANE i & INTERSECTION POINT
100
CONTINUE
ANY INTERFERENCE INDICATORS ON ?
NO
1000
YES
SOLVE FOR NEW LINE OF SIGHT TO ELIMINATE VISUAL INTERFERENCE
WRITE NEW LINE OF SIGHT (EYE) END POINT
SET SWITCH = 1
KT15 = 0 ?
YES
RETURN
NO
1000
SET SWITCH = 0
SET UP LOCAL VARIABLES FOR PHYSICAL INTERFERENCE
D ϕ 1091 ISL=
D ϕ 110
D
CO
CONTINU
RETI

PHYSICAL INTERFERENCE



)91 ISL= 1, 2
D ϕ1100 J = 1, ISTEP
Dϕ1200 I = 1, NLINKS, 2
SOLVE FOR POINT OF INTERSECTION OF LINK I AND SEAT BACK PLANE ISL AT STEP J
SOLUTION EXISTS ?
YES
SET PHYSICAL INTERFERENCE INDICATOR "ON" FOR LINK I
NO
WRITE LINK I AND PLANE ISL AND POINT OF INTERSECTION
1200
CONTINUE
1100
CONTINUE
1091
CONTINUE
RETURN

SWITCH
- 0 ⇒ CONTINUE
- 1 ⇒ BY-PASS VISUAL INTERFERENCE SECTION

KT15
- 0⇒ RECALL PROGRAM MAN 1
- 1⇒ DO NOT RECALL PROGRAM MAN 1

NPLANE	=	NUMBER OF COCKPIT PLANES
ISTEP	=	NUMBER OF STEPS IN TASK
NLINKS	=	NUMBER OF BOEMAN LINKS

2

Figure 6. Interference Analysis Overlay Program Interf.

values. The joint arrays are reset for the next task with BOEMAN's current orientation and position. A flow diagram for this overlay is given in Figure 7.

2.2.6 Output Overlay

Program OUTGO, the output overlay, provides for a printed history of the evaluation run, data for graphs and charts, and a magnetic tape for the validation section. The printed history is divided into three parts:

(1) Input data

(2) Results of task sequence processing

(3) Summation data

Data for charts and graphs are stored on tape to be used generally with another evaluation run for comparison purposes. These data include the numerical performance indicators calculated in the previous overlay (Program SUMM). The data required for validation include BOEMAN's joint locations during each step of a task for which comparable laboratory data exist.

The printed history is generated using the intermediate output file along with control variables (user specified) which determine the amount and kind of history required for the evaluation. These control variables are discussed in Section 3.0 (user's guide). A sample output for the evaluation may be found in Section 3.5 and a flow diagram for Program OUTGO is shown in Figure 8.

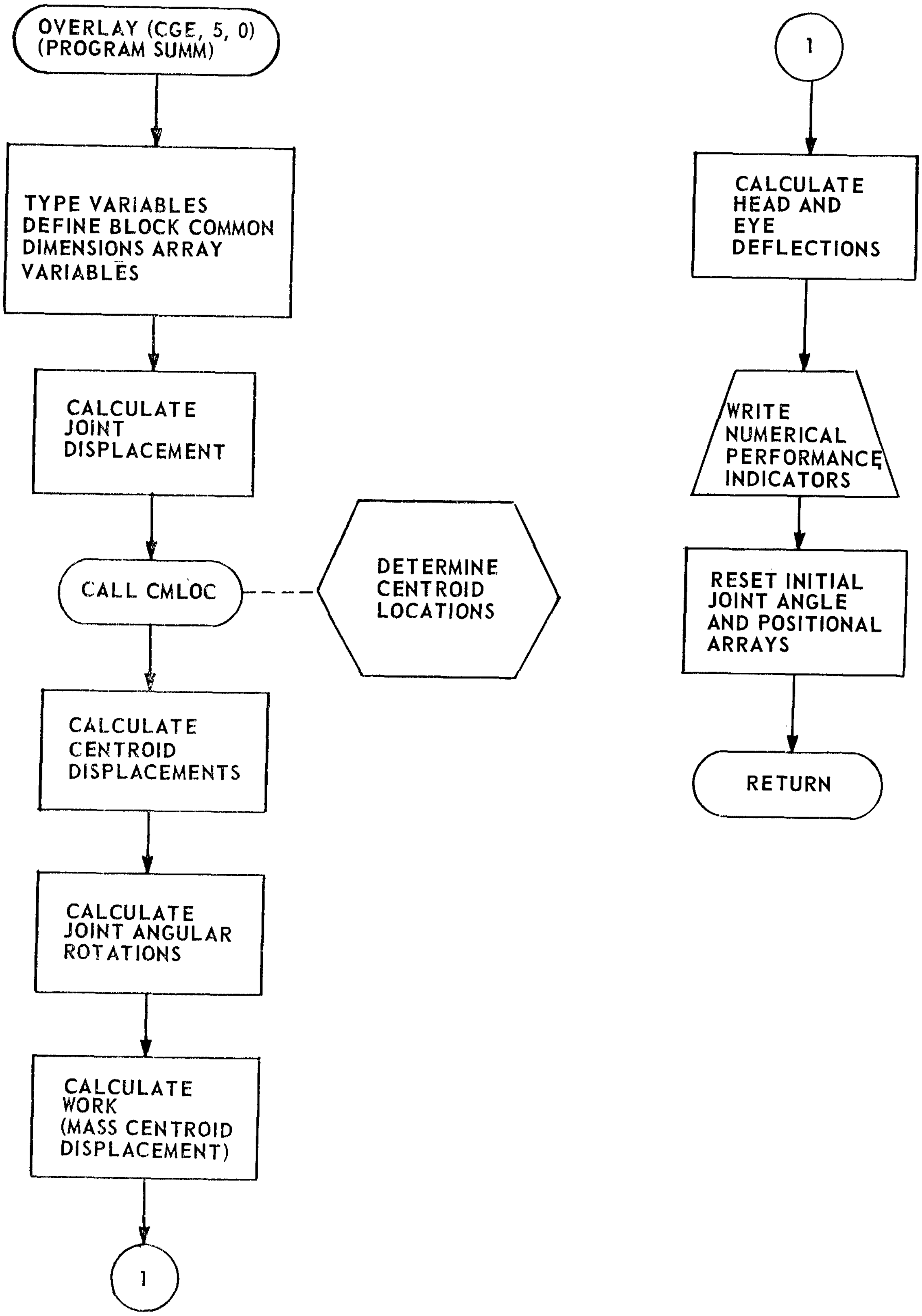


Figure 7. Summation Overlay–Program SUMM

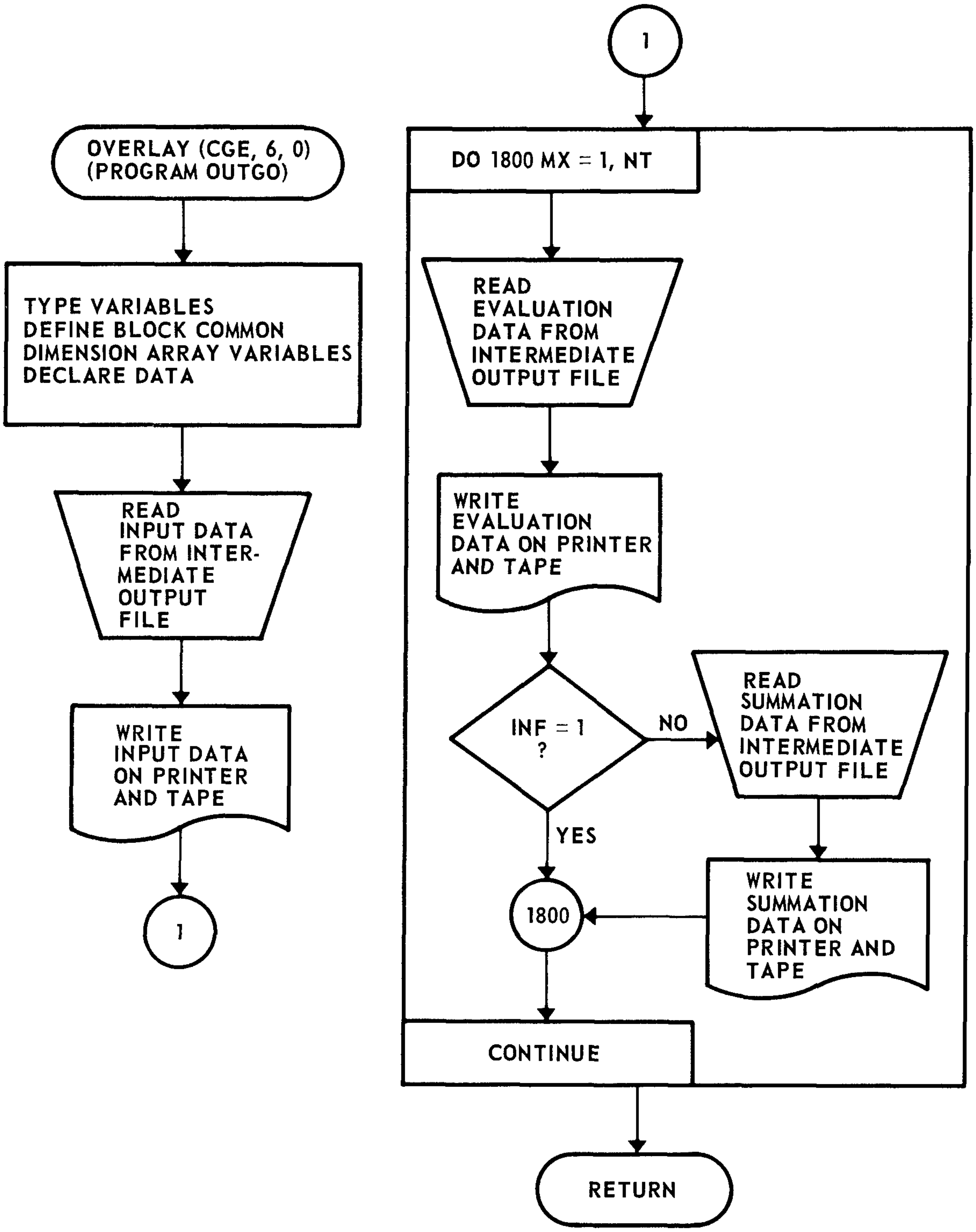

OVERLAY (CGE, 6, 0)
(PROGRAM OUTGO)
TYPE VARIABLES
DEFINE BLOCK COMMON
DIMENSION ARRAY VARIABLES
DECLARE DATA
READ INPUT DATA FROM INTERMEDIATE OUTPUT FILE
WRITE INPUT DATA ON PRINTER AND TAPE
1
1
DO 1800 MX = 1, NT
READ EVALUATION DATA FROM INTERMEDIATE OUTPUT FILE
WRITE EVALUATION DATA ON PRINTER AND TAPE
INF = 1 ?
NO
YES
READ SUMMATION DATA FROM INTERMEDIATE OUTPUT FILE
WRITE SUMMATION DATA ON PRINTER AND TAPE
1800
CONTINUE
RETURN

Figure 8. Output Overlay—Program OUTGO

3.0 USER'S GUIDE

The usage of Programs CAPSIS (Creation section), RAPSIS (Retrieval section), CGE (Evaluation section) and SVØMM (Validation section) is described below with respect to input from cards or tape needed for these programs to operate properly. Following this is a description of the output from each program. Finally errors and diagnostic messages and other machine dependent information are set forth and sample input and output from the program is presented.

3.1 INPUT TO THE PROGRAM

INPUT: PROGRAM CAPSIS

The Creation section (Program CAPSIS) generates a data bank on magnetic tape. The user specifies (on punched cards) the number of data sets to be stored, and an identifying set name delimiting each data set to be stored in the bank. These cards are read from the input file and are stored using the routines from the referenced "DATA POOL" system. The only restriction on the input data is that the content of the data sets must conform to the formats used by Program CGE (INTRAN Overlay). After the tape is written, it will contain all of the above input data and be ready for retrieval. Non-implemented capabilities of this program include adding or deleting data sets or combining two or more data sets to form a new data set. Currently, no portions of data sets may be modified other than by replacement of the entire set. A list of input cards required and their contents (for creating the data bank) is given below:

Cards for First Data Set

Card No.	Columns	Format	Description	Restriction	Sample Value
1	1- 2	I2	NDS = Number of data sets to store	NDS > 0	07
2	1-80	8A10	IT(I) = Identifying set name (I=1,7)	First 12 characters must be TABLEbNAMEb= ; set name may not exceed 10 non-blank (b) characters.	TABLEbNAMEb= LINKSURVEY
3 to M	1-80	8A10	Input (LINKSURVEY) data on (M-2) data cards	Must conform to Overlay INTRAN formats (M-2)	(See sample output tape of CAPSIS)
M+1	1-80	8A10	IT(I) = Terminator of data set (I = 1,7)	First 12 characters must be TABLEbNAMEb= ; Columns 13-80 must be blank (b).	TABLEbNAMEb= b . . . b

Cards 2 through M+1 are repeated using the succeeding set names until NDS sets have been specified and delimited.

INPUT: PROGRAM RAPSIS

The Retrieval section (Program RAPSIS) extracts data via user specified set names. Data may be retrieved from a previously generated data bank by first specifying the number of data sets to be retrieved and then cards specifying an identifying set name for each set required. The only restriction on these sets is that they must be retrieved in the order specified by the INTRAN Overlay (Program CGE). The retrieval data is written on a magnetic tape for use by Program CGE.

Card No.	Columns	Format	Description	Restriction	Sample Value
1	1- 2	I2	NDS - Number of data sets to be retrieved	NDS > 0	07
2	1-10	A10	NUM(1) = 1st set name	NUM ≤ 10 characters	LINKSURVEY
•					
•					
•					
(NDS-1)	1-10	A10	NUM(NDS) = NDSth set name	NUM ≤ 10 characters	COCKPITMMS

Card 2 is repeated until all NDS set names have been specified.

INPUT: PROGRAM CGE

The following input description is partitioned according to CGE card input and tape input from the retrieval program. Both types of data are read by the INTRAN overlay.

CGE Card Input

Data Card 1

Format (16I5)

Column	Name	Description
1- 5	NT	Number of tasks
6-10	NLF	Input file number from which data link is retrieved
11-15	NSF	Input file number for standard position data
16-20	NAF	Input file number for angular limitation data
21-25	NTF	Input file number for task data
26-30	NCF	Input file number for cockpit control codes

Column	Name	Description
31-35	NPF	Input file number for cockpit interference planes
36-40	NOF	Input file number for optimization parameters
41-45	NNF	Input file number for normal distribution table (Input file numbers must agree with 6600 Control Card designations)

Data Cards 2-3

Format (16I5)

Column	Name	Description
1- 5	KT1	0 → Printout input data 1 → Do not print
6-10	KT2	0 → Do not print 1 → Print link dimensions
11-15	KT3	0 → Do not print 1 → Print task data
16-20	KT4	0 → Do not print 1 → Print standard angular position
21-25	KT5	0 → Do not print 1 → Print joint angle limits
26-30	KT6	0 → Do not print 1 → Print cockpit geometry and codes
31-35	KT7	0 → Standard link survey used 1 → Non-standard Survey Used
36-40	KT8	0 → Do not print 1 → Print standard position joint coordinates
41-45	KT9	0 → Do not print 1 → Print control codes (with respect to lumbar joint)
46-50	KT10	0 → Extended hand position tested 1 → Clenched hand position tested
51-55	KT11	Not used as input
56-60	KT12	0 → Do not print 1 → Print reach analysis output

Column	Name	Description	
61-65	KT13	Not currently used	
66-70	KT14	Not used as input	
71-75	KT15	0 → Determine new position for predefined line of sight 1 → Do not calculate new position	
76-80	KT16	Not used as input	
1- 5	KT17	Not currently used	Card 3
6-10	KT18	Not currently used	
11-15	KT19	Not currently used	
16-20	KT20	Not currently used	

Data Cards 4-6

Format (8A10)

Column	Name	Description
1-80	COMENT	Three cards that contain a description of the computer run

Data Card 7

Format (8A10)

Column	Name	Description
1-10	OSERV	Name of alternate link survey (non-standard)

Data Cards 8-12

Format (8F10.0)

Column	Name	Description
1-10	PCT	Percentile value for each link of man-model
11-20		
21-30		
• • •		
71-80		

Data Card 13

Format (3E10.2, 6I5)

Column	Name	Description
1-10	ERR	Allowed error for Davidon minimization (LYNX)
11-20	SCALE	Penalty coefficient scale factor
21-30	ERC	Allowed error in satisfying each equality constraint
31-35	ISKIP	{0 → Optimize first position 1 → First position optimization to be bypassed
36-40	MAN	{0 → Suppress MAN1 output 1 → Allow optimization data output
41-45	IPOSE	{0 → MAN1's position already known 1 → MAN1's position to be calculated from input angles
46-50	NSTEPS	Step size parameter
51-55	NMJ	Maximum number of joints
56-60	IP	Denotes MAN1 error output option

Data Cards 14-23

Format (10F83)

Column	Name	Description
1- 8	CONST	Array of constant Euler angles and weighting coefficients
9-16		Each of these preferred angles and weights is associated with the 27 variable angles of the motion model objective function.
•		
•		
•		
65-72		
73-80		

CGE Tape Input

The following is a description of the format and order of data retrieved from tape, and read by INTRAN.

Link Data

902 Format (XI2/(X2A10,A8,I2,5F10.2))

Card Image #1

Col 1- 2	NL - number of links

Card Image #2

•
•
•

Card Image #NL + 1

Col 1-28	LVØC = 28 character link description
Col 29-30	LN = link number
Col 31-40	LMEAN= mean link length
Col 41-50	LSTD = link length standard deviation
Col 51-60	MMEAN= mean mass
Col 61-70	MSTD = mass standard deviation
Col 71-80	MPCT = percent of link length from proximal end of link to centroid

Normal Distribution Table F = .5 to F = 1.0

903 Format (X16F5.2)

16 values/card image to get 4 card images with 51 values (the positive half of the table)

Task Data

905 Format (I3,7X,7A10/3A10,2F7.3/6F10.1/(I3,7X,7A10/3A10,2F7.3/6F10.1))

Card Image #1

Col 1- 3	TASKNØ	Task number
Col 4-10		Blank
Col 11-80	TDES	70 character task description

Card Image #2

Col 1-10	RHTC	Right hand terminal code
Col 11-20	LHTC	Left hand terminal code
Col 21-30	ETC	Eye terminal code
Col 31-37	TDUR	Task duration time
Col 38-44	THOLD	Holding time at end of task

Card Image #3

Col 1-10	RHØRT	Euler angle for right hand orientation
Col 11-20		
Col 21-30		
Col 31-40	LHØRT	Euler angle for left hand orientation
Col 41-50		
Col 51-60		

Standard Position Data

904 Format (I3/(3F10.1))

Card Image #1

Col 1- 3	NL	Number of links

Card Image #2 to Card Image # (NL + 1)

Col 1-10	THETA	Euler angles to define standard position
Col 11-20	PHI	
Col 21-30	PSI	

Angular Limitations

909 Format (I3/(6F10.1))

Card Image #1

Col 1- 3	NL	Number of links

Card Image #2 to Card Image # (NL + 1)

Col 1-10	Minimum THETA	
Col 11-20	Maximum THETA	Euler angles
Col 21-30	Minimum PHI	
Col 31-40	Maximum PHI	
Col 41-50	Minimum PSI	
Col 51-60	Maximum PSI	

Cockpit Control Codes

906 Format (I3/(A10,3F10.3)

Card Image #1

Col 1- 3	NCC	Number of cockpit control codes

Card Image #2 to Card Image # (NCC + 1)

Col 1-10	TCVOC		10 character description of control point in cockpit
Col 11-20	TCLOC	X	Euclidean coordinate location with respect to cockpit eye reference point
Col 21-30		Y	
Col 31-40		Z	

Cockpit Planes

907 Format (I2/4A10,I2/(9F8.3))

Card Image #1

Col 1- 2	NPL	=	Number of planes in cockpit

Card Image #2

Col 1-40	40 character description of plane
Col 41-42	Number of vertices in plane

Card Image #3 (9F8.3)

Col 1- 9	Euclidean coordinates of vertices
Col 10-18	Three vertices per card - 9 values total
Col 19-27	Repeated for as many vertices
	Repeat Cards #2 and #3 NPL times

INPUT: PROGRAM SVØMM

The following is a description of the input data required by the validation program:

Card No.	Columns	Format	Description	Restriction	Sample Value
1	1- 6	A6	Code = problem identifier	Code = 6HPRØBLM	PRØBLM
	7-16	A10	PN = problem description		WES80DD
	17-21	I5	N = Number of joint coordinates compared	N > 0	bbbb2
	22-26	I5	NR = Number of repetitions	NR > 0	bbb11
	27-31	I5	MX = Maximum order of matrix	MX = 12	bbb12
	32-36	I5	INP ≠ 1 suppress input data		bbbb0
2	1-72	12A6	FMT = Format of input data		(50X,8F10.2)
3 to (3+NR)	1-80	8F10.0	X(I,J) = input data I = Number of joint coordinates compared J = Number of repetitions		(See sample output)

4 + NR	1- 4	A4	Code = data identifier	Code = 4HHYPØ	HYPØ
	11-80	7F10.0	SXM(I) I = 1,N BOEMAN-I data		

3.2 OUTPUT FROM THE PROGRAM

The output from each of the programs is described below. PROGRAMS CAPSIS (Storage) and RAPSIS (Retrieval) provide output on tape only. PROGRAM CGE (Cockpit Geometry Evaluation) provides output on both tape and the printer. PROGRAM SVØMM (Statistical Validation) provides printed output only.

PROGRAM CAPSIS

CAPSIS gives an inventory of the names, locations, lengths and contents of the tables (data sets) created on the file. The data set names used are in the following initial order:

(1)	COCKPITMMS	(Cockpit Plane Vertex Locations)
(2)	TASKSEQ	(Task Sequence Information)
(3)	LINKSURVEY	(Link Survey Data)
(4)	CONTRØLCØD	(Control Codes and Locations)
(5)	ANGLELIMIT	(Upper and Lower Bounds on All Joint Angles)
(6)	SPØSITIØN	(Standard position of all joint angles)
(7)	NØRMALDIST	(Normal distribution table)

The file name used to store these data sets is "BPØØL" or "TAPE10".

PROGRAM RAPSIS

RAPSIS gives an inventory of the names, locations, lengths and contents of the retrieved tables written on a file. The data set names and their order is given by:

(1) LINKSURVEY

(2) NORMALDIST

(3) TASKSEQ

(4) SPØSITION

(5) ANGLELIMIT

(6) CONTRØLCØD

(7) COCKPITMMS

The file name used in retrieval of these data sets is "WØRK" or "TAPE11". In both the storage and retrieval programs, control card language is used to copy these output tapes to the printer.

PROGRAM CGE

Output from CGE100 is written upon four tape files and the printer. The file names and their general contents are:

TAPE 12 = Intermediate output tape (written on by all primary overlays) ("BCD" records)

TAPE 13 = Backup tape (written on by MAN1 and OUTGO Overlays ("BCD" records)

TAPE 14 = MAN1 intermediate positional data during each task for use of OUTGO overlay ("Binary" records)

TAPE 16 = MAN1 intermediate positional data during each task for use by the INTERF overlay ("Binary" record)

TAPE 12 is used to collect all numerical output. It is read by ØUTGØ and printed along with a descriptive and tabular information provided by the OUTGO overlay. Parts of this tape are also to be used by the Validation program as input.

TAPE 13 is the backup tape which yields the original output from MAN1 in case of infeasibility conditions. The printed history of the evaluation may be produced at the option of the user.

TAPE 14 contains joint locations and orientations of BOEMAN-I at each step of the task and is used by the OUTGO overlay to print out all positions prior to an infeasibility condition.

TAPE 16 also contains the joint locations of BOEMAN-I at each step of the task and is used by the INTERF overlay to test for seatback interference.

The printed output is in three parts: Input data, results of task processing, and summation data. It begins with an overall description of the run. The input data portion consists of seven tables:

1. Link Dimensions

   This table provides an ordering of the thirty-six links that describe BOEMAN-I's physique. For each link name and number, the length in inches, the mass percentile, the weight in pounds, the centroid percentage distance from the proximal end and the distance between the link centroid and the proximal ends are printed.

2. Task Sequence

   This table gives the components that make up each task in a flight mission (task sequence). Specified for each task is the right hand, left hand and eye aiming control codes, the duration of the task (in seconds), the duration between tasks, and the right and left hand orientation angles (Euler angles).

3. Standard Position

   The standard orientation of each joint in Euler angles is presented in this table. The joint numbers are the same as the link numbers since each joint corresponds to the proximal end of that link.

4. Joint Angular Limits

This table describes the lower and upper bounds on each Euler angle of each joint. Joints with fixed Euler angles show the same value for the upper and lower bounds. The sign conventions of the angles, Theta, Phi, and Psi, are shown in Figure 9. A rule to be followed is that neither θ or φ may have negative signs at the same joint. In addition, if θ is zero, then that link does not deflect for any value of φ.

5. Cockpit Geometry

This table is in two parts. The first part describes the Cockpit Control Codes. Each control name (coded) and the Euclidean coordinates of that control are listed with the eye reference point as the origin of the coordinate system. The codes are abbreviations for controls according to their function. Appendix VIII lists the full control names with their abbreviations.

The second part provides a description of the cockpit planes by name and with a list of each vertex location in consecutive order. The vertex coordinates are also expressed with respect to the eye reference point.

6. Standard Position

For each joint, the Euclidean coordinates of the standard position are given. These coordinates are with respect to the computer's seat reference point (lumbar joint). In addition, the orientation angles of each joint are given in the standard position.

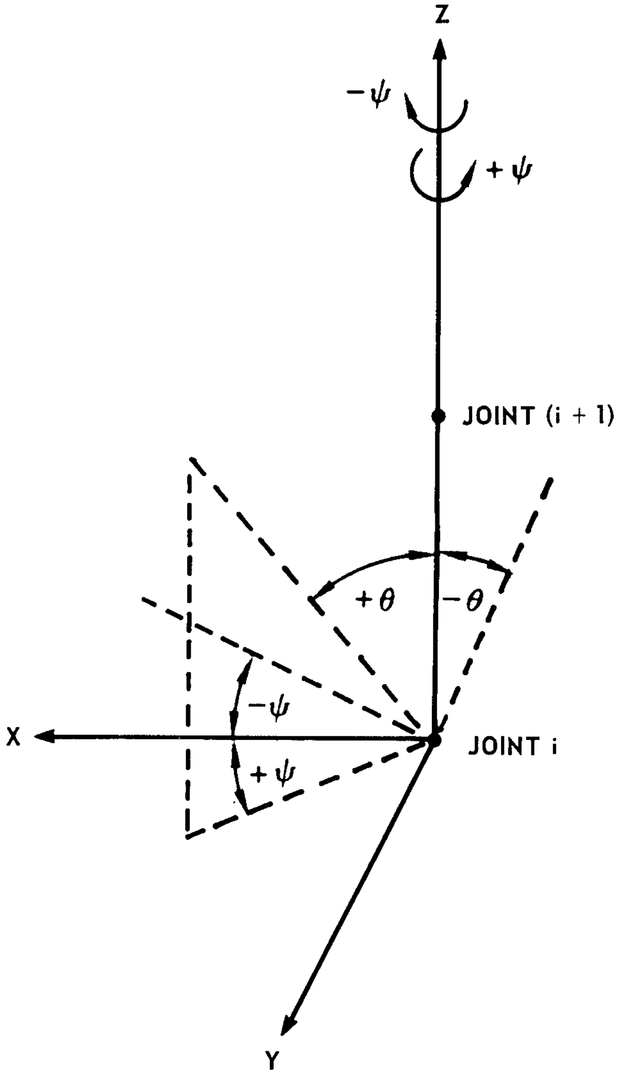


Figure 9. Euler Angle Coordinate System Sign Conventions

7. Cockpit Geometry

This table is the same as Table 5 except that the coordinates use the lumbar joint as the origin rather than the eye reference point.

Part II (task processing) provides the output from the REACHA, MAN1 and INTERF overlays. For each task performed feasibly (no interference), the output consists of BOEMAN's joint locations and orientations at the beginning and at the end of the task.

If the reach analysis deems the task infeasible, it is redefined. The new control locations for each hand are printed, with a corresponding "feasible" top of spine position. The distance from the redefined controls to the original controls are calculated and printed.

If, during the MAN1 optimization, the task becomes infeasible, all positions from the initial to the last feasible position are printed. Following this is a list of joint angles which have exceeded their angular limits. Then the distances of the palms from the final control point positions, along the straight line palm path, are printed.

If during the interference analysis, visual interference occurs, each plane and the intersection location with the line of sight is printed. The new line of sight (two end points) found to correct the blockage is also printed. If physical interference between BOEMAN-I and the seatback plane occurs, the plane and interfering links, the position number during the task, and the intersection point between the link and the seatback are printed.

Part three is the summation section. It provides data by task and cumulatively during the sequence on the joint and centroid displacement for each joint and centroid, the mass-centroid products for each link (giving an indication of work done) with totals for all links. Joint angular deflections (twist only) in degrees and head and eye deflections (total angle) in degrees are also provided. All of the above assumes a feasible task since this section is written only if the task currently being processed is feasible.

PROGRAM SVØMM

SVØMM gives a statistical account of the comparison of BOEMAN-I and real pilot paths. The output begins with the pilot and task identification codes. The real pilot's input data, giving two out of the three coordinates (the third is assumed fixed) of a joint position on its path, repeated n times. The positions of the human may be printed at the option of the evaluator. Following the joint locations of the human is the corresponding man-model synthesized locations (1 repetition). The calculated covariance matrix for the pilot data and the inverse matrix are then recorded. Finally the computed F-value, with the associated degrees-of-freedom are printed. This output scheme is followed for each of the sequenced paths to be tested.

3.3 DIAGNOSTICS AND ERROR MESSAGES

Instead of error messages and diagnostics being interspersed with the printout, a BCD file containing all of the MAN1 calculations is dumped when an infeasible task occurs. Errors occurring in other overlays are usually fatal and the SCOPE 3.0 operating system would abnormally exit. When this occurs, an octal dump of memory is given for that overlay as well as a listing of any input tape (BCD) for error tracing. The only error message occurs in Program SVØMM when a singular matrix is inverted since the F-statistic cannot be calculated. The storage and retrieval programs do not provide diagnostics except for the dumping of input and output files that are used.

3.4 SYSTEM REQUIREMENTS

These programs were written in CDC FORTRAN IV for the CDC 6600 using a Boeing-modified SCOPE 3.1 operating system. No unusual machine components are used other than disc and tape drives (1 input tape and 4 files on disc). The SCOPE 3.1 operating system possesses a flexible control card language which allows for memory, tape and file dumps which are used after an abnormal exit. The control cards for each program are described in the following sections.

PROGRAM CAPSIS

1.	SEQUENCE CARD	(Priority Card)
2.	JOB CARD	(Containing the job name, time estimate, field length estimate)
3.	ACCOUNT CARD	
4.	TAPE REQUEST CARD FOR OUTPUT TAPE "BPØØL"	
5.	COMPILE CARD RUN(S)	(Compile and list)
6.	SETCØRE	(Set all locations in memory to zero)
7.	EXECUTE CARD LGO	
8.	EXIT	(Exit from SCOPE 3.1 operating system)
9.	DMP (0,FL)	(Memory dump of program's field length FL))
10.	EØR	(End of record)

PROGRAM RAPSIS

Same as CAPSIS except:

4. TAPE REQUEST CARDS a) Input tape "BPØØL"
b) Output tape "WORK"

7.1 COPYCR (WORK,ØUTPUT,7)(Work tape is printed out)

REWIND (WORK)

UNLODE (WORK)

DROPFIL (WORK)

PROGRAM CGE

Same as CAPSIS except:

4. TAPE REQUEST CARD TAPE 11 (≡ WØRK) as INPUT

7.1 & 9.1 REWIND (TAPE i)

7.2 & 9.2 COPYSBF (TAPE i, OUTPUT) (TAPE i, i=12,13,14,16 as a file is printed out)

7.3 & 9.3 REWIND (TAPE i)

7.4 & 9.4 REQUEST (TAPES)

7.5 & 9.5 REWIND (TAPES)

7.6 & 9.6 COPYCF (TAPE i, TAPES) (TAPE i as a file is written on magnetic tape)

7.7 & 9.7 REWIND (TAPES)

7.8 & 9.8 DECDUMP (,,,TAPES, 10) (The magnetic tape is printed for comparison)

7.9 & 9.9 UNLØDE (TAPES)

DROPFIL (TAPES)

PROGRAM SVØMM

Program SVØMM is the same as CAPSIS except no tapes are required (i.e., delete tape request card).

Accurate time estimates are not presently available for the execution of all programs. However, the storage and retrieval programs have executed (without compilation) in 16.3 and 15.4 seconds respectively. The Cockpit Geometry Evaluation Program would require about 25 minutes for a 7-task flight mission with each task requiring between 3 and 4 minutes. Compilation requires approximately 30 seconds and the other overlays require about 60 seconds for the entire run. The Validation Program has executed in less than 2 seconds per F-statistic. The CDC uses a 60-bit word for storing numbers, hence the calculations are extremely accurate. Positional coordinates and angular values are given to four decimal places. Cockpit geometry coordinates are accurate to one decimal place.

The most important program restriction is that the retrieved data tape must be written in a format acceptable to the INTRAN overlay. Other pertinent limitations in the present system include the use of no more than 20 tasks per sequence, 27 variable angles, 36 cockpit planes and 36 joints and links of BOEMAN-I.

3.5 SAMPLE INPUT AND OUTPUT

This section is concerned with the sample input and output from the Cockpit Geometry Evaluation Program.

SAMPLE INPUT

a) Card Input

	1 5	6 10	11 15	16 20	21 25	26 30	31 35	36 40	41 45	
Card 1	1	11	11	11	11	11	11	11	11	
	NT	NLF	NSF	NAF	NTF	NCF	NPF	NØF	NNF	

Card 2

1 5	6 10	11 15	16 20	21 25	26 30	31 35	36 40	41 45	46 50	51 55	56 60	61 65	66 70	71 75	76 80
	1	1	1	1	1		1	1						1	
KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10	KT11	KT12	KT13	KT14	KT15	KT16

Card 3

1				
KT17	KT18	KT19	KT20	

Card 4

1

This run is for the multimission simulator using the standard link survey and

CØMENT (I), I = 1,8

Card 5

1

Using a task sequence consisting of 7 tasks

CØMENT (I), I = 9,16

Card 6

1

CØMENT (I), I - 17,24

1 10

OBSERV

Cards 8,9,10, 11

1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80
5.	5.	5.	5.	5.	5.	5.	5.

PCT(I) I = 1,32

Card 12

5.	5.	5.	5.	
PCT(33)	PCT(34)	PCT(35)	PCT(36)	

Card 13

1 10	11 20	21 30	31 35	36 40	41 45	46 50	51	60	
1.E-4	100.	.01	1	0	1	1	27	4	
ERR	SCALE	ERC	ISKIP	MAN	IPOSE	NSTEPS	NMJ	IP	

Card 14

1 8	9 16	17 24	25 32	33 40	41 48	49 56	57 64	65 72	73 80
500.	200.	.0001	500.	100.	.0001	40.	.0001	10.	10.

Weighting Coefficients on Obj. Function

Card 15

10.	10.	.0001	100.	.0001	40.	.0001	10.	10.	10.

Card 16

10.	.0001	25.	.0001	25.	100.	.0001

CONST (I), I - 1,27

Card 16 (Contd)

Preferred Euler Angles

0.	0.	0.

Card 17

0.	0.	0.	90.	0.	0.	45.	0.	-15.	0.

Preferred Euler Angles

Card 18

0.	0.	-90.	0.	0.	45.	0.	15.	0.	90.

Preferred Euler Angles

Card 19

90.	0.	0.	0.	

Preferred Euler Angles

CONST(I) I - 28,54

Cards 20-23

Blank

CONST(I) I - 61,100

b) Tape Input (TAPE 11)

The following listing of TAPE 11 provides the user with the arrangement of the data in each data set:

```
THIS SET OF DATA CONTAINS THE MEAN AND STANDARD DEVIATION FOR BOTH LINK DIMENSIO
N" AND FOR LINK MASS AS WELL AS A PERCENTAGE FOR THE CENTROID LOCATION , FOR EAC
H LINK ON THE BOEMAN FIGURE.
36
LUMBAR LINK                      1      3.70      0.25     11.80      1.50     50.00
DUMMY THORACIC                   2      0.00      0.00      0.00      0.00      0.00
THORACIC LINK                    3     14.40      0.14     37.00      4.71     50.00
NECK LINK,VERTICAL               4      2.20      0.09      0.00      0.00     50.00
NECK LINK,HORIZONTAL             5      1.50      0.00      3.30      0.42     50.00
HEAD LINK                        6      6.00      0.28     11.50      1.46     50.00
EYEMIDPOINT TO HEAD LINK         7      5.50      0.00      0.00      0.00     50.00
UNIT VECTOR FROM EYE             8      1.00      0.00      0.00      0.00      0.00
LEFT EYEBALL TO HEAD             9      5.50      0.00      0.00      0.00     50.00
RIGHT EYEBALL TO HEAD           10      5.50      0.00      0.00      0.00     50.00
INTERCLAVICULAR LINK,LEFT       11      1.00      0.00      0.00      0.00     50.00
INTERCLAVICULAR LINK,RIGHT      12      1.00      0.00      0.00      0.00     50.00
CLAVICULAR LINK,LEFT            13      6.60      0.25      4.90      0.63     50.00
CLAVICULAR LINK,RIGHT           14      6.60      0.25      4.90      0.63     50.00
DUMMY SHOULDER LINK,LEFT        15      0.00      0.00      0.00      0.00     50.00
DUMMY SHOULDER LINK,RIGHT       16      0.00      0.00      0.00      0.00     50.00
HUMERAL LINK,LEFT               17     11.90      0.41      5.20      0.67     46.10
HUMERAL LINK,RIGHT              18     11.90      0.41      5.20      0.67     46.10
RADICAL LINK,LEFT               19     10.70      0.34      2.90      0.38     42.50
RADICAL LINK,RIGHT              20     10.70      0.34      2.90      0.38     42.50
DUMMY HAND LINK,LEFT            21      0.00      0.00      0.00      0.00      0.00
DUMMY HAND LINK,RIGHT           22      0.00      0.00      0.00      0.00      0.00
HAND LINK (EXTENDED),LEFT       23      7.50      0.34      1.30      0.17     47.40
H  D LINK (EXTENDED),RIGHT      24      7.50      0.34      1.30      0.17     47.40
HAND LINK (CLENCHED),LEFT       25      2.80      0.08      1.30      0.17     39.20
HAND LINK (CLENCHED),RIGHT      26      2.80      0.08      1.30      0.17     39.20
PELVIC LINK,LATERAL,LEFT        27      3.80      0.21      9.20      1.17     50.00
PELVIC LINK,LATERAL,RIGHT       28      3.80      0.21      9.20      1.17     50.00
FEMORAL LINK,LEFT               29     17.10      0.66     16.40      2.09     42.70
FEMORAL LINK,RIGHT              30     17.10      0.66     16.40      2.09     42.70
TIBIAL LINK,LEFT                31     16.10      0.71      7.50      0.96     40.40
TIBIAL LINK,RIGHT               32     16.10      0.71      7.50      0.96     40.40
FOOT LINK,LEFT                  33      3.40      0.15      2.60      0.33     58.10
FOOT LINK,RIGHT                 34      3.40      0.15      2.60      0.33     58.10
HEEL-TOE LINK,LEFT              35     10.50      0.45      0.00      0.00     50.00
HEEL-TOE LINK,RIGHT             36     10.50      0.45      0.00      0.00     50.00



THIS DATA SET CONTAINS THE ORDINATE VALUES OF THE NORMAL DISTRIBUTION FROM F=.50
TO F=1.00 NEEDED TO DETERMINE LINK LENGTH AND LINK MASS
 0.00 0.03 0.05 0.08 0.10 0.13 0.15 0.18 0.20 0.23 0.25 0.28 0.31 0.33 0.36 0.39
 0.41 0.44 0.47 0.50 0.53 0.55 0.58 0.61 0.64 0.67 0.71 0.74 0.77 0.81 0.84 0.88
 0.92 0.95 0.99 1.04 1.08 1.13 1.18 1.23 1.28 1.34 1.41 1.48 1.56 1.64 1.75 1.88
   05 2.33 5.00
```

```
THIS SET OF DATA CONTAINS  THE RIGHT HAND CONTROL CODE,THE LEFT HAND CONTROL COD
-E, THE EYE FOCAL POINT CODE,THE TASK DURATION IN SECONDS, THE TASK HOLDING TIME
,AND THE RIGHT AND LEFT HAND ORIENTATION ANGLES  ,FOR EACH TASK IN THE SEQUENCE.
001        STANDARD POSITI N (ANGULAR) TO STARTING POSITION (BOTH HANDS ON STICK)
FCCSC      FCCSC      FCCSC        1.000  1.000
      80.0        85.0      180.0      100.0        95.0      -180.0
002        START POSITION TO LEFT HAND ON THROTTLES,RIGHT HAND ON STICK
FCCSC      FCT        FCT          1.000 10.000
      80.0        85.0      180.0       90.0       110.0       -90.0
003        BRING LEFT HAND FROM THROTTLES TO STICK
FCCSC      FCCSC      FCCSC        1.000  0.001
      80.0        85.0      180.0      100.0        95.0      -180.0
004        BRING RIGHT HAND UP TO MASTER CAUTION BUTTON TO RESET IT
ACAMC      FCCSC      ACAMC        0.900  0.100
     100.0        90.0      110.0      100.0        95.0      -180.0
005        BRING RIGHT HAND TO UTILITY POWER CONTROL ON HYDRAULIC PANEL
MSHP       FCCSC      MSHP         1.500  0.500
     100.0        80.0      170.0      100.0        95.0      -180.0
10         BRING RIGHT HAND BACK TO STICK
FCCSC      FCCSC      FCCSC        1.000  0.001
      80.0        85.0      180.0      100.0        95.0      -180.0
007        BRING LEFT HAND BACK TO THROTTLES
FCCSC      FCT        FCT          1.000 10.000
     100.0        85.0      180.0       90.0       110.0       -90.0
```

```
THIS SET OF DATA CONTAINS BOEMANS STANDARD POSITION IN THE COCKPIT.
36            Θ              φ              ψ
              0.            90.             0.
             20.            90.             0.
             20.            90.             0.
              0.             0.             0.
             90.            90.             0.
             90.            90.             0.
             90.            90.             0.
              0.            90.             0.
             90.           120.             0.
             90.            60.             0.
             90.           180.             0.

             90.             0.             0.
              0.            90.             0.
              0.            90.             0.
           - 30.            90.             0.
           - 30.            90.             0.
            -90.             0.            30.
             90.             0.            30.
             90.            90.             0.
             90.            90.             0.
             10.            90.             0.
             10.            90.             0.
           - 10.            90.             0.
           - 10.            90.             0.
           - 10.            90.             0.
           - 10.            90.             0.
         118.165           180.             0.
         118.165             0.             0.
             90.            90.        -61.835
             90.            90.         61.835
             90.           -90.             0.
             90.           -90.             0.
              0.            90.             0.
              0.            90.             0.
             90.            90.             0.
             90.            90.             0.
```

THIS SET OF DATA CONTAINS THE MINIMUM AND MAXIMUM ANGLES OF JOINT EXCURSION WITH RESPECT TO AN EULERIAN COORDINATE SYSTEM

36 MIN	θ MAX	MIN	φ MAX	MIN	ψ MAX
- 10.	10.	90.	90.	0.	0.
20.	20.	90.	90.	0.	0.
- 40.	40.	0.	180.	- 35.	35.
0.	0.	0.	0.	0.	0.
90.	90.	- 90.	- 90.	0.	0.
30.	150.	0.	180.	- 73.	73.
90.	90.	90.	90.	0.	0.
- 61.	61.	0.	180.	0.	0.
90.	90.	120.	120.	0.	0.
90.	90.	60.	60.	0.	0.
90.	90.	180.	180.	0.	0.
90.	90.	0.	0.	0.	0.
- 10.	10.	0.	180.	0.	0.
- 10.	10.	0.	180.	0.	0.
- 30.	-30.	90.	90.	0.	0.
- 30.	-30.	90.	90.	0.	0.
0.	-180.	0.	180.	-34.	97.
0.	180.	0.	180.	- 97.	34.
0.	142.	90.	90.	-113.	77.
0.	142.	90.	90.	- 77.	113.
10.	10.	90.	90.	0.	0.
10.	10.	90.	90.	0.	0.
- 37.	37.	0.	180.	0.	0.
- 37.	37.	0.	180.	0.	0.
- 37.	37.	0.	180.	0.	0.
- 37.	37.	0.	180.	0.	0.
118.165	118.165	180.	180.	0.	0.
118.165	118.165	0.	0.	0.	0.
48.	132.	0.	180.	-95.835	-22.835
48.	132.	0.	180.	22.835	95.835
0.	113.	-90.	-90.	-35.	43.
0.	113.	-90.	-90.	-43.	35.
- 23.	23.	0.	180.	0.	0.
- 23.	23.	0.	180.	0.	0.
90.	90.	90.	90.	0.	0.
90.	90.	90.	90.	0.	0.

IS SET OF DATA CONTAINS A COCKPIT CONTROL CODE DICTIONARY REFERENCING CONTROL NAMES IN THE MULTI-MISSION SIMULATOR WITH THEIR EUCLIDEAN COORDINATE LOCATIONS WITH RESPECT TO THE COCKPIT EYE REFERENCE POINT.

091	X	Y	Z
FCFWS	-13.6	.25	-31.2
FCEPS	-11.45	-4.35	-31.2
FCRT	-15.8	3.9	-30.45
FCEPT	-15.7	7.5	-29.6
FCCSC	-.66	17.9	-23.2
FCSPS	-11.6	6.1	-30.4
FCT	-13.6	6.68	-30.2
FIRPML	-11.4	26.0	-17.0
FIRPMR	-9.0	26.0	-17.0
FIPT	-.24	16.8	-23.2
FIAT	-.24	16.8	-23.2
FIWSFP	-13.6	.25	-31.2
FIFT	-10.6	27.30	-11.0
FIFI	-10.6	26.82	-13.30
FITSI	-2.6	25.6	-19.2
FIAAT	-6.50	27.8	-8.6
FIAAA	-9.45	26.8	-8.94
FIHUC	0.	18.538	-6.150
FIHUD	0.	28.0	-6.15
FIAI	-6.91	26.0	-12.44
FIAS	-6.46	26.3	-16.3
MM	-6.0	25.6	-18.90
FIVSD	0.	26.36	-15.2
FIVSDSS	-3.50	26.9	-12.4
FIVSDH	3.50	26.9	-12.4
FIVSDI	3.50	25.77	-18.250
FIVSDC	-3.50	25.770	-18.250
FIC	6.1	27.65	-10.28
FIBA	6.48	26.80	-13.1
FIRA	6.55	26.30	-15.8
FIMC	10.2	26.8	-8.94
FIRC	9.50	26.80	-13.1
FIGM	9.00	26.32	-15.4
FIRMI	8.86	25.72	-18.4
FIHSD1	0.	23.0	-28.05
FIHSD2	0.	20.9	-31.9
FIHSDGC	-5.90	24.6	-20.84
FIHSDCI	5.90	24.6	-20.84
AFCSCP	13.75	13.7	-29.15
AFCSSP	10.6	19.30	-30.28
AFCSAP	14.25	19.30	-29.83
AFCADC	15.1	4.51	-31.1

MSESP	-12.50	5.13	-30.5
MSEPS	-15.7	8.4	-29.9
MSLCI	-13.90	-12.41	-32.6
MSLCE	-13.94	-9.2	-32.16
MSLGC	-18.02	20.587	-24.829
MSFMP	-14.50	4.35	-31.6
MSECP	18.3	-9.0	-30.0
MSCPI	18.25	20.5	-25.63
MSLOQ	18.25	23.3	-22.755
MSHP	20.45	-8.0	-28.03
MSAHC	11.90	26.753	-13.573
MSRAT	15.4	22.6	-24.08
MSEBI	15.78	24.6	-21.5
MSMLS	-11.5	8.43	-30.2
MSAS	-13.5	8.38	-29.9
DCMSCP	20.84	-4.6	-29.1
DCMRHAWI	9.44	27.45	-10.2
DCMLWI	10.66	27.16	-11.4
DCMEDSP	14.56	26.48	-14.8
ACAMC	3.533	27.283	-11.108
ACAEFL	-4.0	27.9	-16.14
ACAEFR	4.0	27.9	-16.14
ACALP	14.13	25.7	-18.38
A LFW	-8.4	26.6	-9.42
ACAWW	-3.18	27.25	-11.04
ACALAW	3.80	25.0	-19.20
WSAIS	-18.5	-9.54	-30.2
WSMP	-19.0	-4.6	-29.10
WSASP	-19.5	16.75	-25.75
WSMAS	-19.08	22.10	-22.30
WSGS	-19.90	19.20	-25.05
WSWS	-15.56	22.48	-23.0
WSSPS	-18.0	-12.7	-31.1
WSSPAI	-18.03	-13.82	-31.15
WSEJ	-19.080	23.781	-21.745
WSLLLTV	14.0	21.0	-26.88
CNIMPS	-18.375	6.25	-28.6
CNIMSS	-21.375	3.22	-25.7
CNITS	-20.8	11.95	-25.0
CNIICSP	-19.5	15.2	-25.95
CNIRBC	19.48	16.56	-25.4
CNIDLR	12.65	24.6	-21.47
CNIDLC	13.30	24.0	-23.72
CNINMS	18.2	14.04	-27.2
CNILOS	20.84	5.22	-25.70
CNIDSS	22.3	5.2	-29.5
CNINDP	13.90	9.8	-29.64
CNIHTTD	6.050	25.70	-18.578
IMDS	12.75	-9.08	-32.3

```
THIS DATA SET CONTAINS EACH SET OF VERTICES CORRESPONDING TO EACH COCKPIT PLANE
IN THE MULTI-MISSION SIMULATOR COCKPIT
36    X       Y        Z        X        Y        Z        X        Y        Z
UPPER FRONT PANEL                                  06
  -17.720  25.349 -20.230 -17.720  26.817 -13.322 - 4.250  28.368 - 6.027
   4.250  28.368 - 6.027  17.720  26.817 -13.322  17.720  25.349 -20.230
LOWER FRONT PANEL (CENTER)                         04
 - 2.250  24.540 -21.011 - 2.250  25.349 -20.230   2.250  25.349 -20.230
   2.250  24.540 -21.011
LOWER FRONT PANEL (LEFT CENTER)                    05
 -16.770  23.101 -22.401 -16.770  25.349 -20.230 - 2.250  25.349 -20.230
 - 2.250  24.540 -21.011 - 4.500  23.101 -22.401
LOWER FRONT PANEL (RIGHT CENTER)                   05
   4.500  23.101 -22.401   2.250  24.540 -21.011   2.250  25.349 -20.230
  16.770  25.349 -20.230  16.770  23.101 -22.401
LOWER FRONT PANEL (LEFT WING)                      05
 -17.132  17.808 -27.859 -21.897  22.971 -22.537 -18.080  25.349 -20.230
 -16.770  25.349 -20.230 -16.770  17.808 -27.859
LOWER FRONT PANEL (RIGHT WING)                     05
  16.770  17.808 -27.859  16.770  25.349 -20.230  18.080  25.349 -20.230
  21.897  22.971 -22.537  17.132  17.808 -27.859
LOWER FRONT PANEL (LOWER LEFT CENTER)              04
 -16.770  20.314 -25.093 -16.770  23.101 -22.401 -12.020  23.101 -22.401
 -12.020  20.314 -25.093
LOWER FRONT PANEL (LOWER RIGHT CENTER)             04
  12.020  20.314 -25.093  12.020  23.101 -22.401  16.770  23.101 -22.401
  16.770  20.314 -25.093
CIRCULAR SCOPE                                     06
   0.000  19.769 -32.343 - 4.630  21.376 -30.210 - 4.630  24.602 -25.930
   0.000  26.209 -23.797 - 4.630  24.602 -25.930   4.630  21.376 -30.210
HEAD UP DISPLAY PANEL (FRONT)                      04
 - 2.000  18.188 - 8.229 - 2.000  19.071 - 4.071   2.000  19.071 - 4.071
   2.000  18.188 - 8.229
HEAD UP DISPLAY PANEL (LEFT SIDE)                  04
 - 2.750  27.480 -10.204 - 2.750  28.368 - 6.027 - 2.000  19.071 - 4.071
 - 2.000  18.188 - 8.229
HEAD UP DISPLAY PANEL (TOP SIDE)                   04
 - 2.000  19.071 - 4.071   2.000  19.071 - 4.071   2.750  28.368 - 6.027
 - 2.750  28.368 - 6.027
HEAD UP DISPLAY PANEL (RIGHT SIDE)                 04
   2.000  19.071 - 4.071   2.750  28.368 - 6.027   2.750  27.480 -10.204
   2.000  18.188 - 8.229
HEAD UP DISPLAY PANEL (BOTTOM SIDE)                04
   2.000  18.188 - 8.229   2.750  27.480 -10.204 - 2.750  27.480 -10.204
 - 2.000  18.188 - 8.229
UPPER LEFT SIDE PANEL                              04
 -17.125 -14.201 -32.230 -17.125  17.922 -28.001 -21.898  22.975 -22.522
 -21.899 -14.824 -27.498
LOWER LEFT SIDE PANEL                              04
 -10.405 -14.080 -33.392 -10.426  16.904 -29.320 -17.074  17.887 -28.008
 -17.052 -14.238 -32.231
UPPER RIGHT SIDE PANEL                             04
  17.125  17.711 -27.988  21.898  22.789 -22.505  21.898 -15.134 -27.498
  17.125 -14.511 -32.230
LOWER RIGHT SIDE PANEL                             04
  10.431  16.604 -29.311  17.079  17.686 -27.987  17.058 -14.537 -32.222
  10.410 -14.330 -33.384
```

```
CONTROL STICK PLATFORM (TOP SIDE)          04
 - 2.750  13.149 -28.230   2.750  13.149 -28.230   2.750  19.149 -28.230
 - 2.750  19.149 -28.230
 ONTROL STICK PLATFORM (LEFT SIDE)         04
 - 2.750  13.149 -37.730 - 2.750  13.149 -28.230 - 2.750  19.149 -28.230
 - 2.750  19.149 -37.730
CONTROL STICK PLATFORM (FRONT SIDE)        04
   2.750  13.149 -37.730   2.750  13.149 -28.230 - 2.750  13.149 -28.230
 - 2.750  13.149 -37.730
CONTROL STICK PLATFORM (RIGHT SIDE)        04
   2.750  19.149 -37.730   2.750  19.149 -28.230   2.750  13.149 -28.230
   2.750  13.149 -37.730
CONTROL STICK PLATFORM (BACK SIDE)         04
 - 2.750  19.149 -37.730 - 2.750  19.149 -28.230   2.750  19.149 -28.230
   2.750  19.149 -37.730
SEAT PLANE (LEFT SIDE)                     05
 - 8.500 - 4.751 -37.730 - 8.500 - 4.751 -32.370 - 8.500   8.009 -31.090
 - 8.500   8.609 -31.930 - 8.500   8.609 -37.730
SEAT PLANE (FRONT SIDE)                    04
 - 8.500   8.609 -37.730 - 8.500   8.609 -31.930   8.500   8.609 -31.930
   8.500   8.609 -37.730
SEAT PLANE (RIGHT SIDE)                    05
   8.500   8.609 -37.730   8.500   8.609 -31.930   8.500   8.009 -31.090
   8.500 - 4.751 -32.370   8.500 - 4.751 -37.730
SEAT PLANE (FRONT-TOP BEVEL)               04
 - 8.500   8.609 -31.930 - 8.500   8.009 -31.090   8.500   8.009 -31.090
   8.500   8.609 -31.930
SEAT PLANE (TOP)                           04
 - 8.500   8.009 -31.090 - 8.500 - 4.751 -32.370   8.500 - 4.751 -32.370
   8.500   8.009 -31.090
SEATBACK PLANE (LOWER FRONT)               04
 - 8.500 - 4.751 -32.370 - 8.500 -10.751 - 4.370   8.500 -10.751 - 4.370
   8.500 - 4.751 -32.370
SEATBACK PLANE (UPPER FRONT)               04
 - 8.500 -10.751 - 4.370 - 8.500 -10.751   3.630   8.500 -10.751   3.630
   8.500 -10.751 - 4.370
FLOOR                                      04
 -21.897 -15.000 -37.730  21.897 -15.000 -37.730  21.897  30.000 -37.730
 -21.897  30.000 -37.730
CEILING                                    04
 -21.897 -15.000  10.000  21.897 -15.000  10.000  21.897  30.000  10.000
 -21.897 -15.000  10.000
BACK WALL                                  04
 -21.897 -15.000 -37.730 -21.897 -15.000  10.000  21.897 -15.000  10.000
  21.897 -15.000 -37.730
RIGHT SIDE WALL                            04
  21.897 -15.000 -37.730  21.897 -15.000  10.000  21.897  30.000  10.000
  21.897  30.000 -37.730
FRONT WALL                                 04
  21.897  30.000 -37.730  21.897  30.000  10.000 -21.897  30.000  10.000
 -21.897  30.000 -37.730
LEFT SIDE WALL                             04
 -21.897  30.000 -37.730 -21.897  30.000  10.000 -21.897 -15.000  10.000
 -21.897 -15.000 -37.730
```

SAMPLE ØUTPUT

The following listing gives the initial and final positions of BOEMAN-I during Task 1. This task requires that he move from standard position to the throttles. No interference is encountered and the task is deemed feasible by the REACHA overlay.

```
COCKPIT GEOMETRY EVALUATION PROGRAM

BOEMAN * * * * * * * *  PHASE I
```

PART I INPUT DATA

THIS RUN IS FOR THE MULTIMISSION SIMULATOR USING THE STANDARD LINK SURVEY AND USING A TASK SEQUENCE CONSISTING OF 7 TASKS

1. LINK DIMENSIONS

		LINK		MASS		CENTROID DISTANCE FROM PROXIMAL END	
	LINK NAME	PERCENTILE	LENGTH (INCHES)	PERCENTILE	WEIGHT (POUNDS)	PERCENTAGE	LENGTH (INCHES)
1	LUMBAR LINK	5.0	3.3	5.0	9.3	50.0	1.6
2	DUMMY THORACIC	5.0	0.0	5.0	0.0	0.0	0.0
3	THORACIC LINK	5.0	14.2	5.0	29.3	50.0	7.1
4	NECK LINK,VERTICAL	5.0	2.0	5.0	0.0	50.0	1.0
5	NECK LINK,HORIZONTAL	5.0	1.5	5.0	2.6	50.0	.8
6	HEAD LINK	5.0	5.5	5.0	9.1	50.0	2.8
7	EYEMIDPOINT TO HEAD LINK	5.0	5.5	5.0	0.0	50.0	2.8
8	UNIT VECTOR FROM EYE	5.0	1.0	5.0	0.0	0.0	0.0
9	LEFT EYEBALL TO HEAD	5.0	5.5	5.0	0.0	50.0	2.8
10	RIGHT EYERALL TO HEAD	5.0	5.5	5.0	0.0	50.0	2.8
11	INTERCLAVICULAR LINK,LEFT	5.0	1.0	5.0	0.0	50.0	.5
12	INTERCLAVICULAR LINK,RIGHT	5.0	1.0	5.0	0.0	50.0	.5
13	CLAVICULAR LINK,LEFT	5.0	6.2	5.0	3.9	50.0	3.1
14	CLAVICULAR LINK,RIGHT	5.0	6.2	5.0	3.9	50.0	3.1
15	DUMMY SHOULDER LINK,LEFT	5.0	0.0	5.0	0.0	50.0	0.0
16	DUMMY SHOULDER LINK,RIGHT	5.0	0.0	5.0	0.0	50.0	0.0
17	HUMERAL LINK,LEFT	5.0	11.2	5.0	4.1	46.1	5.2
18	HUMERAL LINK,RIGHT	5.0	11.2	5.0	4.1	46.1	5.2

19	RADICAL LINK,LEFT	5.0	10.1	5.0	2.3	42.5	4.3
20	RADICAL LINK,RIGHT	5.0	10.1	5.0	2.3	42.5	4.3
21	DUMMY HAND LINK,LEFT	5.0	0.0	5.0	0.0	0.0	0.0
22	DUMMY HAND LINK,RIGHT	5.0	0.0	5.0	0.0	0.0	0.0
23	HAND LINK (EXTENDED),LEFT	5.0	6.9	5.0	1.0	47.4	3.3
24	HAND LINK (EXTENDED),RIGHT	5.0	6.9	5.0	1.0	47.4	3.3
25	HAND LINK (CLENCHED),LEFT	5.0	2.7	5.0	1.0	39.2	1.0
26	HAND LINK (CLENCHED),RIGHT	5.0	2.7	5.0	1.0	39.2	1.0
27	PELVIC LINK,LATERAL,LEFT	5.0	3.5	5.0	7.3	50.0	1.7
28	PELVIC LINK,LATERAL,RIGHT	5.0	3.5	5.0	7.3	50.0	1.7
29	FEMORAL LINK,LEFT	5.0	16.0	5.0	13.0	42.7	6.8
30	FEMORAL LINK,RIGHT	5.0	16.0	5.0	13.0	42.7	6.8
31	TIBIAL LINK,LEFT	5.0	14.9	5.0	5.9	40.4	6.0
32	TIBIAL LINK,RIGHT	5.0	14.9	5.0	5.9	40.4	6.0
33	FOOT LINK,LEFT	5.0	3.2	5.0	2.1	58.1	1.8
34	FOOT LINK,RIGHT	5.0	3.2	5.0	2.1	58.1	1.8
35	HEEL-TOE LINK,LEFT	5.0	9.8	5.0	0.0	50.0	4.9
36	HEEL-TOE LINK,RIGHT	5.0	9.8	5.0	0.0	50.0	4.9

PART 1

INPUT DATA

CONTINUED

2. TASK SEQUENCE

TASK NO.	RIGHT HAND CONTROL	LEFT HAND CONTROL	EYE AIMING POINT	TASK DURATION (SEC)	DURATION BETWEEN TASKS (SEC)
1	FCCSC	FCCSC	FCCSC	1.000	1.000
2	FCCSC	FCT	FCT	1.000	10.000
3	FCCSC	FCCSC	FCCSC	1.000	.001
4	ACAMC	FCCSC	ACAMC	.900	.100
5	MSHP	FCCSC	MSHP	1.500	.500
6	FCCSC	FCCSC	FCCSC	1.000	.001
7	FCCSC	FCT	FCT	1.000	10.000

```
 RIGHT HAND ORIENTATION               LEFT HAND ORIENTATION

     (EULER ANGLES)                       (EULER ANGLES)

 (   80.0,    85.0,   180.0)  (  100.0,    95.0, -180.0)
 (   80.0,    85.0,   180.0)  (   90.0,   110.0,  -90.0)
 (   80.0,    85.0,   180.0)  (  100.0,    95.0, -180.0)
 (  100.0,    90.0,   110.0)  (  100.0,    95.0, -180.0)
 (  100.0,    80.0,   170.0)  (  100.0,    95.0, -180.0)
 (   80.0,    85.0,   180.0)  (  100.0,    95.0, -180.0)
 (  100.0,    85.0,   180.0)  (   90.0,   110.0,  -90.0)
```

2

PART I

INPUT DATA
CONTINUED

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3. STANDARD POSITION

   JOINT                 ORIENTATION ANGLES
    NO.                   (EULER ANGLES)

     1             (    0.0,   90.0,    0.0)
     2             (   20.0,   90.0,    0.0)
     3             (  -20.0,   90.0,    0.0)
     4             (    0.0,    0.0,    0.0)
     5             (   90.0,  -90.0,    0.0)
     6             (   90.0,   90.0,    0.0)
     7             (   90.0,   90.0,    0.0)

     8             (    0.0,   90.0,    0.0)
     9             (   90.0,  120.0,    0.0)
    10             (   90.0,   60.0,    0.0)
    11             (   90.0,  180.0,    0.0)
    12             (   90.0,    0.0,    0.0)
    13             (    0.0,   90.0,    0.0)
    14             (    0.0,   90.0,    0.0)
    15             (  -30.0,   90.0,    0.0)
    16             (  -30.0,   90.0,    0.0)
    17             (  -90.0,    0.0,   30.0)
    18             (   90.0,    0.0,  -30.0)
    19             (   90.0,   90.0,    0.0)
    20             (   90.0,   90.0,    0.0)
    21             (   10.0,   90.0,    0.0)
    22             (   10.0,   90.0,    0.0)
    23             (  -10.0,   90.0,    0.0)
    24             (  -10.0,   90.0,    0.0)
    25             (  -10.0,   90.0,    0.0)
    26             (  -10.0,   90.0,    0.0)
    27             (  118.2,  180.0,    0.0)
    28             (  118.2,    0.0,    0.0)
    29             (   90.0,   90.0,  -61.8)
    30             (   90.0,   90.0,   61.8)
    31             (   90.0,  -90.0,    0.0)
    32             (   90.0,  -90.0,    0.0)
    33             (    0.0,   90.0,    0.0)
    34             (    0.0,   90.0,    0.0)
    35             (   90.0,   90.0,    0.0)
    36             (   90.0,   90.0,    0.0)
```

4. JOINT ANGULAR LIMITS

JOINT	THETA		PHI		PSI	
NO.	MIN	MAX	MIN	MAX	MIN	MAX
1	-10.0	10.0	90.0	90.0	0.0	0.0
2	20.0	20.0	90.0	90.0	0.0	0.0
3	-40.0	40.0	0.0	180.0	-35.0	35.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	90.0	90.0	-90.0	-90.0	0.0	0.0
6	30.0	150.0	0.0	180.0	-73.0	73.0
7	90.0	90.0	90.0	90.0	0.0	0.0
8	-61.0	61.0	0.0	180.0	0.0	0.0
9	90.0	90.0	120.0	120.0	0.0	0.0
10	90.0	90.0	60.0	60.0	0.0	0.0
11	90.0	90.0	180.0	180.0	0.0	0.0
12	90.0	90.0	0.0	0.0	0.0	0.0
13	-10.0	10.0	0.0	180.0	0.0	0.0
14	-10.0	10.0	0.0	180.0	0.0	0.0
15	-30.0	-30.0	90.0	90.0	0.0	0.0
16	-30.0	-30.0	90.0	90.0	0.0	0.0
17	-180.0	0.0	0.0	180.0	-34.0	97.0
18	0.0	180.0	0.0	180.0	-97.0	34.0
19	0.0	142.0	90.0	90.0	-113.0	77.0
20	0.0	142.0	90.0	90.0	-77.0	113.0
21	10.0	10.0	90.0	90.0	0.0	0.0
22	10.0	10.0	90.0	90.0	0.0	0.0
23	-37.0	37.0	0.0	180.0	0.0	0.0
24	-37.0	37.0	0.0	180.0	0.0	0.0
25	-37.0	37.0	0.0	180.0	0.0	0.0
26	-37.0	37.0	0.0	180.0	0.0	0.0
27	118.2	118.2	180.0	180.0	0.0	0.0
28	118.2	118.2	0.0	0.0	0.0	0.0
29	48.0	132.0	0.0	180.0	-95.8	-22.8
30	48.0	132.0	0.0	180.0	22.8	95.8
31	0.0	113.0	-90.0	-90.0	-35.0	43.0
32	0.0	113.0	-90.0	-90.0	-43.0	35.0
33	-23.0	23.0	0.0	180.0	0.0	0.0
34	-23.0	23.0	0.0	180.0	0.0	0.0
35	90.0	90.0	90.0	90.0	0.0	0.0
36	90.0	90.0	90.0	90.0	0.0	0.0

PART I

INPUT DATA
CONTINUED

5. COCKPIT GEOMETRY

COCKPIT DESIGN USED IS THEMULTI-MISSION SIMULATOR. CONTROL LOCATION COORDINATES ARE WITH RESPECT TO THE EYE REFERENCE POINT AND ARE IN INCHES.

A. COCKPIT CONTROL CODES

CONTROL NAME	LOCATION OF CONTROL
FCFWS	(-13.600, .250, -31.200)
FCEPS	(-11.450, -4.350, -31.200)
FCRT	(-15.800, 3.900, -30.450)
FCEPT	(-15.700, 7.500, -29.600)
FCCSC	(-.660, 17.900, -23.200)
FCSPS	(-11.600, 6.100, -30.400)
FCI	(-13.600, 6.680, -30.200)
FIRPML	(-11.400, 26.000, -17.000)
FIRPMR	(-9.000, 26.000, -17.000)
FIPT	(-.240, 16.800, -23.200)
FIAT	(-.240, 16.800, -23.200)
FIWSFP	(-13.600, .250, -31.200)
FIFT	(-10.600, 27.300, -11.000)
FIFI	(-10.600, 26.820, -13.300)
FITSI	(-2.600, 25.600, -19.200)
FIAAT	(-6.500, 27.800, -8.600)
FIAAA	(-9.450, 26.800, -8.940)
FIHUC	(0.000, 18.538, -6.150)
FIHUD	(0.000, 28.000, -6.150)
FIAI	(-6.910, 26.000, -12.440)
FIAS	(-6.460, 26.300, -16.300)
FIMM	(-6.000, 25.600, -18.900)
FIVSD	(0.000, 26.360, -15.200)
FIVSDSS	(-3.500, 26.900, -12.400)
FIVSDH	(3.500, 26.900, -12.400)
FIVSDI	(3.500, 25.770, -18.250)
FIVSDC	(-3.500, 25.770, -18.250)
FIC	(6.100, 27.650, -10.280)
FIBA	(6.480, 26.800, -13.100)
FIRA	(6.550, 26.300, -15.800)
FIMC	(10.200, 26.800, -8.940)
FIRC	(9.500, 26.800, -13.100)
FIGM	(9.000, 26.320, -15.400)
FIRMI	(8.860, 25.720, -18.400)
FIHSD1	(0.000, 23.000, -28.050)
FIHSD2	(0.000, 20.900, -31.900)
FIHSDGC	(-5.900, 24.600, -20.840)
FIHSDCI	(5.900, 24.600, -20.840)
AFCSCP	(13.750, 13.700, -29.150)

```
AFCSSP     (  10.600,   19.300,  -30.280)
AFCSAP     (  14.250,   19.300,  -29.830)
AFCADC     (  15.100,    4.510,  -31.100)

MSESP      ( -12.500,    5.130,  -30.500)
MSEPS      ( -15.700,    8.400,  -29.900)
MSLCI      ( -13.900,  -12.480,  -32.600)
MSLCF      ( -13.940,   -9.200,  -32.160)
MSLGC      ( -18.020,   20.587,  -24.829)
MSEMP      ( -14.500,    4.350,  -31.600)
MSECP      (  18.300,   -9.000,  -30.000)
MSCPI      (  18.250,   20.500,  -25.630)
MSLOQ      (  18.250,   23.300,  -22.755)
MSHP       (  20.450,   -8.000,  -28.030)
MSAHC      (  11.900,   26.753,  -13.573)
MSRAT      (  15.400,   22.600,  -24.080)
MSERI      (  15.780,   24.600,  -21.500)
MSMLS      ( -11.500,    8.430,  -30.200)
MSAS       ( -13.500,    8.380,  -29.900)
DCMSCP     (  20.840,   -4.600,  -29.100)
DCMRHAWI   (   9.440,   27.450,  -10.200)
DCMLWI     (  10.660,   27.160,  -11.400)
DCMEDSP    (  14.560,   26.480,  -14.800)
ACAMC      (   3.533,   27.288,  -11.108)
ACAEFL     (  -4.000,   27.900,  -16.140)
ACAEFR     (   4.000,   27.900,  -16.140)
ACALP      (  14.130,   25.700,  -18.380)
ACALFW     (  -8.400,   26.600,   -9.420)
ACAWW      (  -3.180,   27.250,  -11.040)
ACALAW     (   3.800,   25.000,  -19.200)
WSATS      ( -18.500,   -9.540,  -30.200)
WSMP       ( -19.000,   -4.600,  -29.100)
WSASP      ( -19.500,   16.750,  -25.750)
WSMAS      ( -19.080,   22.100,  -22.300)
WSGS       ( -19.900,   19.200,  -25.050)
WSWS       ( -15.560,   22.480,  -23.000)
WSSPS      ( -18.000,  -12.700,  -31.100)
WSSPAI     ( -18.030,  -13.820,  -31.150)
WSEJ       ( -19.080,   23.781,  -21.745)
WSLLLTV    (  14.000,   21.000,  -26.880)
CNIMPS     ( -18.375,    6.250,  -28.600)
CNIMSS     ( -21.375,    3.220,  -25.700)
CNITS      ( -20.800,   11.950,  -25.000)
CNIICSP    ( -19.500,   15.200,  -25.950)
CNIRBC     (  19.480,   16.560,  -25.400)
CNIDLR     (  12.650,   24.600,  -21.470)
CNIDLC     (  13.300,   24.000,  -23.720)
CNINMS     (  18.200,   14.040,  -27.200)
CNILOS     (  20.840,    5.220,  -25.700)
CNIDSS     (  22.300,    5.200,  -29.500)
CNINDP     (  13.900,    9.800,  -29.640)
CNIHTTD    (   6.050,   25.700,  -18.578)
CNIMDS     (  12.750,   -9.080,  -32.300)
```

PART I

INPUT DATA
CONTINUED

B. COCKPIT PLANES

THE PLANE VERTICES ARE WITH RESPECT TO THE EYE REFERENCE POINT AND ARE IN (X,Y,Z) COORDINATES.

PLANE	VERTICES
UPPER FRONT PANEL	
	(-17.720, 25.349, -20.230)
	(-17.720, 26.817, -13.322)
	(-4.250, 28.368, -6.027)
	(4.250, 28.368, -6.027)
	(17.720, 26.817, -13.322)
	(17.720, 25.349, -20.230)
LOWER FRONT PANEL (CENTER)	
	(-2.250, 24.540, -21.011)
	(-2.250, 25.349, -20.230)
	(2.250, 25.349, -20.230)
	(2.250, 24.540, -21.011)
LOWER FRONT PANEL (LEFT CENTER)	
	(-16.770, 23.101, -22.401)
	(-16.770, 25.349, -20.230)
	(-2.250, 25.349, -20.230)
	(-2.250, 24.540, -21.011)
	(-4.500, 23.101, -22.401)
LOWER FRONT PANEL (RIGHT CENTER)	
	(4.500, 23.101, -22.401)
	(2.250, 24.540, -21.011)
	(2.250, 25.349, -20.230)
	(16.770, 25.349, -20.230)
	(16.770, 23.101, -22.401)
LOWER FRONT PANEL (LEFT WING)	
	(-17.132, 17.808, -27.859)
	(-21.897, 22.971, -22.537)
	(-18.080, 25.349, -20.230)
	(-16.770, 25.349, -20.230)
	(-16.770, 17.808, -27.859)
LOWER FRONT PANEL (RIGHT WING)	
	(16.770, 17.808, -27.859)
	(16.770, 25.349, -20.230)
	(18.080, 25.349, -20.230)
	(21.897, 22.971, -22.537)
	(17.132, 17.808, -27.859)
LOWER FRONT PANEL (LOWER LEFT CENTER)	
	(-16.770, 20.314, -25.093)
	(-16.770, 23.101, -22.401)
	(-12.020, 23.101, -22.401)
	(-12.020, 20.314, -25.093)

LOWER FRONT PANEL (LOWER RIGHT CENTER)	(12.020, 20.314, -25.093)
	(12.020, 23.101, -22.401)
	(16.770, 23.101, -22.401)
	(16.770, 20.314, -25.093)
CIRCULAR SCOPE	(0.000, 19.769, -32.343)
	(-4.630, 21.376, -30.210)
	(-4.630, 24.602, -25.930)
	(0.000, 26.209, -23.797)
	(-4.630, 24.602, -25.930)
	(4.630, 21.376, -30.210)
HEAD UP DISPLAY PANEL (FRONT)	(-2.000, 18.188, -8.229)
	(-2.000, 19.071, -4.071)
	(2.000, 19.071, -4.071)
	(2.000, 18.188, -8.229)
HEAD UP DISPLAY PANEL (LEFT SIDE)	(-2.750, 27.480, -10.204)
	(-2.750, 28.368, -6.027)
	(-2.000, 19.071, -4.071)
	(-2.000, 18.188, -8.229)
HEAD UP DISPLAY PANEL (TOP SIDE)	(-2.000, 19.071, -4.071)
	(2.000, 19.071, -4.071)
	(2.750, 28.368, -6.027)
	(-2.750, 28.368, -6.027)
HEAD UP DISPLAY PANEL (RIGHT SIDE)	(2.000, 19.071, -4.071)
	(2.750, 28.368, -6.027)
	(2.750, 27.480, -10.204)
	(2.000, 18.188, -8.229)
HEAD UP DISPLAY PANEL (BOTTOM SIDE)	(2.000, 18.188, -8.229)
	(2.750, 27.480, -10.204)
	(-2.750, 27.480, -10.204)
	(-2.000, 18.188, -8.229)
UPPER LEFT SIDE PANEL	(-17.125, -14.201, -32.230)
	(-17.125, 17.922, -28.001)
	(-21.898, 22.975, -22.522)
	(-21.899, -14.824, -27.498)
LOWER LEFT SIDE PANEL	(-10.405, -14.080, -33.392)
	(-10.426, 16.904, -29.320)
	(-17.074, 17.887, -28.008)
	(-17.052, -14.238, -32.231)
UPPER RIGHT SIDE PANEL	(17.125, 17.711, -27.988)
	(21.898, 22.789, -22.505)
	(21.898, -15.134, -27.498)
	(17.125, -14.511, -32.230)

```
LOWER RIGHT SIDE PANEL
                                          ( 10.431,  16.604, -29.311)
                                          ( 17.079,  17.686, -27.987)
                                          ( 17.058, -14.537, -32.222)
                                          ( 10.410, -14.380, -33.384)
CONTROL STICK PLATFORM (TOP SIDE)
                                          ( -2.750,  13.149, -28.230)
                                          (  2.750,  13.149, -28.230)
                                          (  2.750,  19.149, -28.230)
                                          ( -2.750,  19.149, -28.230)
CONTROL STICK PLATFORM (LEFT SIDE)
                                          ( -2.750,  13.149, -37.730)
                                          ( -2.750,  13.149, -28.230)
                                          ( -2.750,  19.149, -28.230)
                                          ( -2.750,  19.149, -37.730)
CONTROL STICK PLATFORM (FRONT SIDE)
                                          (  2.750,  13.149, -37.730)
                                          (  2.750,  13.149, -28.230)
                                          ( -2.750,  13.149, -28.230)
                                          ( -2.750,  13.149, -37.730)
CONTROL STICK PLATFORM (RIGHT SIDE)
                                          (  2.750,  19.149, -37.730)
                                          (  2.750,  19.149, -28.230)
                                          (  2.750,  13.149, -28.230)
                                          (  2.750,  13.149, -37.730)
CONTROL STICK PLATFORM (BACK SIDE)
                                          ( -2.750,  19.149, -37.730)
                                          ( -2.750,  19.149, -28.230)
                                          (  2.750,  19.149, -28.230)
                                          (  2.750,  19.149, -37.730)
SEAT PLANE (LEFT SIDE)
                                          ( -8.500,  -4.751, -37.730)
                                          ( -8.500,  -4.751, -32.370)
                                          ( -8.500,   8.009, -31.090)
                                          ( -8.500,   8.609, -31.930)
                                          ( -8.500,   8.609, -37.730)
SEAT PLANE (FRONT SIDE)
                                          ( -8.500,   8.609, -37.730)
                                          ( -8.500,   8.609, -31.930)
                                          (  8.500,   8.609, -31.930)
                                          (  8.500,   8.609, -37.730)
SEAT PLANE (RIGHT SIDE)
                                          (  8.500,   8.609, -37.730)
                                          (  8.500,   8.609, -31.930)
                                          (  8.500,   8.009, -31.090)
                                          (  8.500,  -4.751, -32.370)
                                          (  8.500,  -4.751, -37.730)
SEAT PLANE (FRONT-TOP BEVEL)
                                          ( -8.500,   8.609, -31.930)
                                          ( -8.500,   8.009, -31.090)
                                          (  8.500,   8.009, -31.090)
                                          (  8.500,   8.609, -31.930)
SEAT PLANE (TOP)
                                          ( -8.500,   8.009, -31.090)
                                          ( -8.500,  -4.751, -32.370)
                                          (  8.500,  -4.751, -32.370)
                                          (  8.500,   8.009, -31.090)
```

```
SEATBACK PLANE (LOWER FRONT)
                                          (  -8.500,  -4.751, -37.370)
                                          (  -8.500, -10.751,  -4.370)
                                          (   8.500, -10.751,  -4.370)
                                          (   8.500,  -4.751, -37.370)
SEATBACK PLANE (UPPER FRONT)
                                          (  -8.500, -10.751,  -4.370)

                                          (  -8.500, -10.751,   3.630)
                                          (   8.500, -10.751,   3.630)
                                          (   8.500, -10.751,  -4.370)
FLOOR
                                          ( -21.897, -15.000, -37.730)
                                          (  21.897, -15.000, -37.730)
                                          (  21.897,  30.000, -37.730)
                                          ( -21.897,  30.000, -37.730)
CEILING
                                          ( -21.897, -15.000,  10.000)
                                          (  21.897, -15.000,  10.000)
                                          (  21.897,  30.000,  10.000)
                                          ( -21.897, -15.000,  10.000)
BACK WALL
                                          ( -21.897, -15.000, -37.730)
                                          ( -21.897, -15.000,  10.000)
                                          (  21.897, -15.000,  10.000)
                                          (  21.897, -15.000, -37.730)
RIGHT SIDE WALL
                                          (  21.897, -15.000, -37.730)
                                          (  21.897, -15.000,  10.000)
                                          (  21.897,  30.000,  10.000)
                                          (  21.897,  30.000, -37.730)
FRONT WALL
                                          (  21.897,  30.000, -37.730)
                                          (  21.897,  30.000,  10.000)
                                          ( -21.897,  30.000,  10.000)
                                          ( -21.897,  30.000, -37.730)
LEFT SIDE WALL
                                          ( -21.897,  30.000, -37.730)
                                          ( -21.897,  30.000,  10.000)
                                          ( -21.897, -15.000,  10.000)
                                          ( -21.897, -15.000, -37.730)
```

PART I

INPUT DATA
CONTINUED

THE SEAT REFERENCE POINT IS LOCATED AT (0.000, -4.000, -25.054) WITH RESPECT TO THE EYE REFERENCE POINT.

6. STANDARD POSITION

JOINT NO.	(X,Y,Z) COORDINATES
1	(0.0, 0.0, 3.3)
2	(0.0, 0.0, 3.3)
3	(-0.0, 0.0, 17.5)
4	(-0.0, 0.0, 19.5)
5	(-0.0, -1.5, 19.5)
6	(-0.0, -1.5, 25.0)
7	(-0.0, 4.0, 25.0)
8	(-0.0, 5.0, 25.0)
9	(-2.8, 4.0, 25.0)
10	(2.8, 4.0, 25.0)
11	(-1.0, 0.0, 17.5)
12	(1.0, 0.0, 17.5)
13	(-7.2, 0.0, 17.5)
14	(7.2, 0.0, 17.5)
15	(-7.2, 0.0, 17.5)
16	(7.2, 0.0, 17.5)
17	(-7.2, 0.0, 6.2)
18	(7.2, 0.0, 6.2)
19	(-7.2, 10.1, 6.2)
20	(7.2, 10.1, 6.2)
21	(-7.2, 10.1, 6.2)
22	(7.2, 10.1, 6.2)
23	(-7.2, 17.1, 6.2)
24	(7.2, 17.1, 6.2)
25	(-7.2, 12.8, 6.2)
26	(7.2, 12.8, 6.2)
27	(-3.0, -0.0, -1.6)
28	(3.0, 0.0, -1.6)
29	(-3.0, 16.0, -1.6)
30	(3.0, 16.0, -1.6)
31	(-3.0, 16.0, -16.6)
32	(3.0, 16.0, -16.6)
33	(-3.0, 16.0, -19.7)
34	(3.0, 16.0, -16.6)
35	(-3.0, 25.8, -19.7)
36	(3.0, 16.0, -16.6)

PART I

INPUT DATA CONTINUED

7. COCKPIT GEOMETRY

CONTROL LOCATION COORDINATES ARE WITH RESPECT TO THE SEAT REFERENCE POINT AND ARE IN INCHES.

A. COCKPIT CONTROL CODES

CONTROL NAME (CODE)	LOCATION OF CONTROL (X,Y,Z) COORDINATES
FCFWS	(-13.600, 4.250, -6.146)
FCEPS	(-11.450, -.350, -6.146)
FCRT	(-15.800, 7.900, -5.396)
FCEPT	(-15.700, 11.500, -4.546)
FCCSC	(-.660, 21.900, 1.854)
FCSPS	(-11.600, 10.100, -5.346)
FCT	(-13.600, 10.680, -5.146)
FIRPML	(-11.400, 30.000, 8.054)
FIRPMR	(-9.000, 30.000, 8.054)
FIPT	(-.240, 20.800, 1.854)
FIAT	(-.240, 20.800, 1.854)
FIWSFP	(-13.600, 4.250, -6.146)
FIFT	(-10.600, 31.300, 14.054)
FIFI	(-10.600, 30.820, 11.754)
FITSI	(-2.600, 29.600, 5.854)
FIAAT	(-6.500, 31.800, 16.454)
FIAAA	(-9.450, 30.800, 16.114)
FIHUC	(0.000, 22.538, 18.904)
FIHUD	(0.000, 32.000, 18.904)
FIAI	(-6.910, 30.000, 12.614)
FIAS	(-6.460, 30.300, 8.754)
FIMM	(-6.000, 29.600, 6.154)
FIVSD	(0.000, 30.360, 9.854)
FIVSDSS	(-3.500, 30.900, 12.654)
FIVSDH	(3.500, 30.900, 12.654)
FIVSDI	(3.500, 29.770, 6.804)
FIVSDC	(-3.500, 29.770, 6.804)
FIC	(6.100, 31.650, 14.774)
FIBA	(6.480, 30.800, 11.954)
FIRA	(6.550, 30.300, 9.254)
FIMC	(10.200, 30.800, 16.114)
FIRC	(9.500, 30.800, 11.954)
FIGM	(9.000, 30.320, 9.654)
FIRMI	(8.860, 29.720, 6.654)
FIHSD1	(0.000, 27.000, -2.996)
FIHSD2	(0.000, 24.900, -6.846)
FIHSDGC	(-5.900, 28.600, 4.214)
FIHSDCI	(5.900, 28.600, 4.214)
AFCSCP	(13.750, 17.700, -4.096)
AFCSSP	(10.600, 23.300, -5.226)
AFCSAP	(14.250, 23.300, -4.776)
AFCADC	(15.100, 8.510, -6.046)
MSESP	(-12.500, 9.130, -5.446)

```
MSEPS        ( -15.700,   12.400,   -4.846)
MSLCI        ( -13.900,   -8.480,   -7.546)
MSLCE        ( -13.940,   -5.200,   -7.106)
MSLGC        ( -18.020,   24.587,     .225)
MSFMP        ( -14.500,    8.350,   -6.546)
MSECP        (  18.300,   -5.000,   -4.946)
MSCPI        (  18.250,   24.500,    -.576)
MSLOQ        (  18.250,   27.300,    2.299)
MSHP         (  20.450,   -4.000,   -2.976)
MSAHC        (  11.900,   30.753,   11.481)
MSHAT        (  15.400,   26.600,     .974)
MSEBT        (  15.780,   28.600,    3.554)
MSHLS        ( -11.500,   12.430,   -5.146)
MSAS         ( -13.500,   12.380,   -4.846)
DCMSCP       (  20.840,    -.600,   -4.046)
DCMRHAWI     (   9.440,   31.450,   14.854)
DCMLWI       (  10.660,   31.160,   13.654)
DCMEDSP      (  14.560,   30.480,   10.254)
ACAMC        (   3.533,   31.288,   13.946)
ACAEFL       (  -4.000,   31.900,    8.914)
ACAEFR       (   4.000,   31.900,    8.914)
ACALP        (  14.130,   29.700,    6.674)
ACALFW       (  -8.400,   30.600,   15.634)

ACAWW        (  -3.180,   31.250,   14.014)
ACALAW       (   3.800,   29.000,    5.854)
WSAIS        ( -18.500,   -5.540,   -5.146)
WSMP         ( -19.000,    -.600,   -4.046)
WSASP        ( -19.500,   20.750,    -.696)
WSMAS        ( -19.080,   26.100,    2.754)
WSGS         ( -19.900,   23.200,     .004)
WSWS         ( -15.560,   26.480,    2.054)
WSSPS        ( -18.000,   -8.700,   -6.046)
WSSPAI       ( -18.030,   -9.820,   -6.096)
WSEJ         ( -19.080,   27.781,    3.309)
WSLLLTV      (  14.000,   25.000,   -1.826)
CNIMPS       ( -18.375,   10.250,   -3.546)
CNIMSS       ( -21.375,    7.220,    -.646)
CNITS        ( -20.800,   15.950,     .054)
CNIICSP      ( -19.500,   19.200,    -.896)
CNIRBC       (  19.480,   20.560,    -.346)
CNIDLR       (  12.650,   28.600,    3.584)
CNIDLC       (  13.300,   28.000,    1.334)
CNINMS       (  18.200,   18.040,   -2.146)
CNILOS       (  20.840,    9.220,    -.646)
CNIDSS       (  22.300,    9.200,   -4.446)
CNINDP       (  13.900,   13.800,   -4.586)
CNIHTTD      (   6.050,   29.700,    6.476)
CNIMDS       (  12.750,   -5.080,   -7.246)
```

PART I

INPUT DATA CONTINUED

B. COCKPIT PLANES

THE PLANE VERTICES ARE WITH RESPECT TO THE SEAT REFERENCE POINT AND ARE IN (X,Y,Z) COORDINATES,

PLANE	VERTICES
UPPER FRONT PANEL	(-17.720, 29.349, 4.824)
	(-17.720, 30.817, 11.732)
	(-4.250, 32.368, 19.027)
	(4.250, 32.368, 19.027)
	(17.720, 30.817, 11.732)
	(17.720, 29.349, 4.824)
LOWER FRONT PANEL (CENTER)	(-2.250, 28.540, 4.043)
	(-2.250, 29.349, 4.824)
	(2.250, 29.349, 4.824)
	(2.250, 28.540, 4.043)
LOWER FRONT PANEL (LEFT CENTER)	(-16.770, 27.101, 2.653)
	(-16.770, 29.349, 4.824)
	(-2.250, 29.349, 4.824)
	(-2.250, 28.540, 4.043)
	(-4.500, 27.101, 2.653)
LOWER FRONT PANEL (RIGHT CENTER)	(4.500, 27.101, 2.653)
	(2.250, 28.540, 4.043)
	(2.250, 29.349, 4.824)
	(16.770, 29.349, 4.824)
	(16.770, 27.101, 2.653)
LOWER FRONT PANEL (LEFT WING)	(-17.132, 21.808, -2.805)
	(-21.897, 26.971, 2.517)
	(-18.080, 29.349, 4.824)
	(-16.770, 29.349, 4.824)
	(-16.770, 21.808, -2.805)
LOWER FRONT PANEL (RIGHT WING)	(16.770, 21.808, -2.805)
	(16.770, 29.349, 4.824)
	(18.080, 29.349, 4.824)
	(21.897, 26.971, 2.517)
	(17.132, 21.808, -2.805)
LOWER FRONT PANEL (LOWER LEFT CENTER)	(-16.770, 24.314, -.039)
	(-16.770, 27.101, 2.653)
	(-12.020, 27.101, 2.653)
	(-12.020, 24.314, -.039)

```
LOWER FRONT PANEL (LOWER RIGHT CENTER)
                                            (  12.020,  24.314,   -.039)
                                            (  12.020,  27.101,   2.653)
                                            (  16.770,  27.101,   2.653)
                                            (  16.770,  24.314,   -.039)
CIRCULAR SCOPE
                                            (   0.000,  23.769,  -7.289)
                                            (  -4.630,  25.376,  -5.156)
                                            (  -4.630,  28.602,   -.876)
                                            (   0.000,  30.209,   1.257)
                                            (  -4.630,  28.602,   -.876)
                                            (   4.630,  25.376,  -5.156)
HEAD UP DISPLAY PANEL (FRONT)
                                            (  -2.000,  22.188,  16.825)
                                            (  -2.000,  23.071,  20.983)
                                            (   2.000,  23.071,  20.983)
                                            (   2.000,  22.188,  16.825)
HEAD UP DISPLAY PANEL (LEFT SIDE)
                                            (  -2.750,  31.480,  14.850)
                                            (  -2.750,  32.368,  19.027)
                                            (  -2.000,  23.071,  20.983)
                                            (  -2.000,  22.188,  16.825)
HEAD UP DISPLAY PANEL (TOP SIDE)
                                            (  -2.000,  23.071,  20.983)
                                            (   2.000,  23.071,  20.983)
                                            (   2.750,  32.368,  19.027)
                                            (  -2.750,  32.368,  19.027)
HEAD UP DISPLAY PANEL (RIGHT SIDE)
                                            (   2.000,  23.071,  20.983)
                                            (   2.750,  32.368,  19.027)
                                            (   2.750,  31.480,  14.850)
                                            (   2.000,  22.188,  16.825)
HEAD UP DISPLAY PANEL (BOTTOM SIDE)
                                            (   2.000,  22.188,  16.825)
                                            (   2.750,  31.480,  14.850)
                                            (  -2.750,  31.480,  14.850)
                                            (  -2.000,  22.188,  16.825)
UPPER LEFT SIDE PANEL
                                            ( -17.125, -10.201,  -7.176)
                                            ( -17.125,  21.922,  -2.947)
                                            ( -21.898,  26.975,   2.532)
                                            ( -21.899, -10.824,  -2.444)
LOWER LEFT SIDE PANEL
                                            ( -10.405, -10.080,  -8.338)
                                            ( -10.426,  20.904,  -4.266)
                                            ( -17.074,  21.887,  -2.954)
                                            ( -17.052, -10.238,  -7.177)
UPPER RIGHT SIDE PANEL
                                            (  17.125,  21.711,  -2.934)
                                            (  21.898,  26.789,   2.549)
                                            (  21.898, -11.134,  -2.444)
                                            (  17.125, -10.511,  -7.176)
LOWER RIGHT SIDE PANEL
                                            (  10.431,  20.604,  -4.257)
                                            (  17.079,  21.686,  -2.933)
                                            (  17.058, -10.537,  -7.168)
                                            (  10.410, -10.380,  -8.330)
```

CONTROL STICK PLATFORM (TOP SIDE)	(-2.750,	17.149,	-3.176)
	(2.750,	17.149,	-3.176)
	(2.750,	23.149,	-3.176)
	(-2.750,	23.149,	-3.176)
CONTROL STICK PLATFORM (LEFT SIDE)	(-2.750,	17.149,	-12.676)
	(-2.750,	17.149,	-3.176)
	(-2.750,	23.149,	-3.176)
	(-2.750,	23.149,	-12.676)
CONTROL STICK PLATFORM (FRONT SIDE)	(2.750,	17.149,	-12.676)
	(2.750,	17.149,	-3.176)
	(-2.750,	17.149,	-3.176)
	(-2.750,	17.149,	-12.676)
CONTROL STICK PLATFORM (RIGHT SIDE)	(2.750,	23.149,	-12.676)
	(2.750,	23.149,	-3.176)
	(2.750,	17.149,	-3.176)
	(2.750,	17.149,	-12.676)
CONTROL STICK PLATFORM (BACK SIDE)	(-2.750,	23.149,	-12.676)
	(-2.750,	23.149,	-3.176)
	(2.750,	23.149,	-3.176)
	(2.750,	23.149,	-12.676)
SEAT PLANE (LEFT SIDE)	(-8.500,	-.751,	-12.676)
	(-8.500,	-.751,	-7.316)
	(-8.500,	12.009,	-6.036)
	(-8.500,	12.609,	-6.876)
	(-8.500,	12.609,	-12.676)
SEAT PLANE (FRONT SIDE)	(-8.500,	12.609,	-12.676)
	(-8.500,	12.609,	-6.876)
	(8.500,	12.609,	-6.876)
	(8.500,	12.609,	-12.676)
SEAT PLANE (RIGHT SIDE)	(8.500,	12.609,	-12.676)
	(8.500,	12.609,	-6.876)
	(8.500,	12.009,	-6.036)
	(8.500,	-.751,	-7.316)
	(8.500,	-.751,	-12.676)
SEAT PLANE (FRONT-TOP BEVEL)	(-8.500,	12.609,	-6.876)
	(-8.500,	12.009,	-6.036)
	(8.500,	12.009,	-6.036)
	(8.500,	12.609,	-6.876)
SEAT PLANE (TOP)	(-8.500,	12.009,	-6.036)
	(-8.500,	-.751,	-7.316)
	(8.500,	-.751,	-7.316)
	(8.500,	12.009,	-6.036)

```
SEATBACK PLANE (LOWER FRONT)

                                   (  -8.500,   -.751,  -7.316)
                                   (  -8.500,  -6.751,  20.684)
                                   (   8.500,  -6.751,  20.684)
                                   (   8.500,   -.751,  -7.316)
SEATBACK PLANE (UPPER FRONT)
                                   (  -8.500,  -6.751,  20.684)
                                   (  -8.500,  -6.751,  28.684)
                                   (   8.500,  -6.751,  28.684)
                                   (   8.500,  -6.751,  20.684)
FLOOR
                                   ( -21.897, -11.000, -12.676)
                                   (  21.897, -11.000, -12.676)
                                   (  21.897,  34.000, -12.676)
                                   ( -21.897,  34.000, -12.676)
CEILING
                                   ( -21.897, -11.000,  35.054)
                                   (  21.897, -11.000,  35.054)
                                   (  21.897,  34.000,  35.054)
                                   ( -21.897, -11.000,  35.054)
BACK WALL
                                   ( -21.897, -11.000, -12.676)
                                   ( -21.897, -11.000,  35.054)
                                   (  21.897, -11.000,  35.054)
                                   (  21.897, -11.000, -12.676)
RIGHT SIDE WALL
                                   (  21.897, -11.000, -12.676)
                                   (  21.897, -11.000,  35.054)
                                   (  21.897,  34.000,  35.054)
                                   (  21.897,  34.000, -12.676)
FRONT WALL
                                   (  21.897,  34.000, -12.676)
                                   (  21.897,  34.000,  35.054)
                                   ( -21.897,  34.000,  35.054)
                                   ( -21.897,  34.000, -12.676)
LEFT SIDE WALL
                                   ( -21.897,  34.000, -12.676)
                                   ( -21.897,  34.000,  35.054)
                                   ( -21.897, -11.000,  35.054)
                                   ( -21.897, -11.000, -12.676)
                                   PART 2

                             PROCESSING TASK   1

                                POSITION   1

JOINT NO.  EUCLIDEAN COORDINATES (INCHES)      ANGULAR COORDINATES (DEGREES)

     1    (   0.000,    0.000,    3.290)     (   0.000,  90.000,    0.000)
     2    (   0.000,    0.000,    3.290)     (  20.000,  90.000,    0.000)
     3    (   -.000,     .000,   17.460)     ( -20.000,  90.000,    0.000)
     4    (   -.000,     .000,   19.513)     (   0.000,   0.000,    0.000)
     5    (   -.000,   -1.500,   19.513)     (  90.000, -90.000,    0.000)
     6    (   -.000,   -1.500,   25.054)     (  90.000,  90.000,    0.000)
     7    (   -.000,    4.000,   25.054)     (  90.000,  90.000,    0.000)
     8    (   -.000,    5.000,   25.054)     (   0.000,  90.000,    0.000)
     9    (  -2.847,    4.000,   25.054)     (  90.000, 120.000,    0.000)
    10    (   2.847,    4.000,   25.054)     (  90.000,  60.000,    0.000)
    11    (  -1.000,     .000,   17.460)     (  90.000, 180.000,    0.000)
    12    (   1.000,     .000,   17.460)     (  90.000,   0.000,    0.000)
    13    (  -7.190,     .000,   17.460)     (   0.000,  90.000,    0.000)
    14    (   7.190,     .000,   17.460)     (   0.000,  90.000,    0.000)
    15    (  -7.190,     .000,   17.460)     ( -30.000,  90.000,    0.000)
    16    (   7.190,     .000,   17.460)     ( -30.000,  90.000,    0.000)
    17    (  -7.190,     .000,    6.233)     ( -90.000,   0.000,   30.000)
    18    (   7.190,     .000,    6.233)     (  90.000,   0.000,  -30.000)
    19    (  -7.190,   10.142,    6.233)     (  90.000,  90.000,    0.000)
    20    (   7.190,   10.142,    6.233)     (  90.000,  90.000,    0.000)
    21    (  -7.190,   10.142,    6.233)     (  10.000,  90.000,    0.000)
    22    (   7.190,   10.142,    6.233)     (  10.000,  90.000,    0.000)
    23    (  -7.190,   17.085,    6.233)     ( -10.000,  90.000,    0.000)
    24    (   7.190,   17.085,    6.233)     ( -10.000,  90.000,    0.000)
    25    (  -7.190,   12.811,    6.233)     ( -10.000,  90.000,    0.000)
    26    (   7.190,   12.811,    6.233)     ( -10.000,  90.000,    0.000)
    27    (  -3.050,   -0.000,   -1.630)     ( 118.165, 180.000,    0.000)
    28    (   3.050,    0.000,   -1.630)     ( 118.165,   0.000,    0.000)
    29    (  -3.050,   16.020,   -1.630)     (  90.000,  90.000,  -61.835)
    30    (   3.050,   16.020,   -1.630)     (  90.000,  90.000,   61.835)
    31    (  -3.050,   16.020,  -16.570)     (  90.000, -90.000,    0.000)
    32    (   3.050,   16.020,  -16.570)     (  90.000, -90.000,    0.000)
    33    (  -3.050,   16.020,  -19.720)     (   0.000,  90.000,    0.000)
    34    (   3.050,   16.020,  -16.570)     (   0.000,  90.000,    0.000)
    35    (  -3.050,   25.780,  -19.720)     (  90.000,  90.000,    0.000)
    36    (   3.050,   16.020,  -16.570)     (  90.000,  90.000,    0.000)
```

POSITION 6

JOINT NO.	EUCLIDEAN COORDINATES (INCHES)			ANGULAR COORDINATES (DEGREES)		
1	.000	-.527	3.247	-9.224	90.000	0.000
2	.000	-.527	3.247	20.000	90.000	0.000
3	-.471	4.202	16.597	-8.934	282.356	-7.210
4	-.539	4.887	18.531	0.000	0.000	0.000
5	-.731	3.482	19.021	90.000	-90.000	0.000
6	-.210	7.523	22.776	118.241	85.878	2.603
7	-.331	11.274	18.756	90.000	90.000	0.000
8	-.363	11.889	17.968	5.124	91.301	0.000
9	-3.057	4.676	19.929	90.000	120.000	0.000
10	2.637	10.370	25.623	90.000	60.000	0.000
11	-1.462	4.311	16.523	90.000	180.000	0.000
12	.520	4.092	16.671	90.000	0.000	0.000
13	-7.558	5.169	15.874	2.461	117.654	0.000
14	6.695	4.220	16.252	-11.046	241.967	0.000
15	-7.558	5.169	15.874	-30.000	90.000	0.000
16	6.695	4.220	16.252	-30.000	90.000	0.000
17	-6.546	6.402	4.760	-101.101	-23.691	14.716
18	4.688	7.163	5.604	112.143	28.047	-1.106
19	-3.272	15.513	1.735	64.976	90.000	-14.257
20	3.066	16.081	1.054	46.830	90.000	18.892
21	-3.272	15.513	1.735	10.000	90.000	0.000
22	3.066	16.081	1.054	10.000	90.000	0.000
23	-.676	21.951	1.834	10.030	137.821	0.000
24	-.624	21.906	1.859	-36.306	192.918	0.000
25	-1.674	19.476	1.796	-10.000	90.000	0.000
26	.794	19.667	1.550	-10.000	90.000	0.000
27	-3.050	-0.000	-1.630	118.165	180.000	0.000
28	3.050	0.000	-1.630	118.165	0.000	0.000
29	-3.050	16.020	-1.630	90.000	90.000	-61.835
30	3.050	16.020	-1.630	90.000	90.000	61.835
31	-3.050	16.020	-16.570	90.000	-90.000	0.000
32	3.050	16.020	-16.570	90.000	-90.000	0.000
33	-3.050	16.020	-19.720	0.000	90.000	0.000
34	3.050	16.020	-16.570	0.000	90.000	0.000
35	-3.050	25.780	-19.720	90.000	90.000	0.000
36	3.050	16.020	-16.570	90.000	90.000	0.000

```
                    PART 3

               SUMMATICN OF TASK  1

     JOINT AND CENTROID DISPLACEMENTS

                         TASK DISPLACEMENT   CUMULATIVE DISPLACEMENT

      JOINT  1                  .529                      .529
   CENTROID  1                  .265                      .265

      JOINT  2                  .529                      .529
   CENTROID  2                  .529                      .529

      JOINT  3                 4.315                     4.315
   CENTROID  3                 1.907                     1.907

      JOINT  4                 5.013                     5.013
   CENTROID  4                 4.664                     4.664

      JOINT  5                 5.059                     5.059
   CENTROID  5                 5.029                     5.029

      JOINT  6                 9.308                     9.308
   CENTROID  6                 7.154                     7.154

      JOINT  7                 9.627                     9.627
   CENTROID  7                 9.212                     9.212

      JOINT  8                 9.889                     9.889
   CENTROID  8                 9.627                     9.627

      JOINT  9                 5.173                     5.173
   CENTROID  9                 0.000                     0.000

      JOINT 10                 6.399                     6.399
   CENTROID 10                 0.000                     0.000

      JOINT 11                 4.436                     4.436
   CENTROID 11                 4.376                     4.376

      JOINT 12                 4.195                     4.195

   CENTROID 12                 4.255                     4.255

      JOINT 13                 5.419                     5.419
   CENTROID 13                 4.923                     4.923
```

```
     JOINT 14                 4.417                     4.417
  CENTROID 14                 4.302                     4.302


     JOINT 15                 5.419                     5.419
  CENTROID 15                 5.419                     5.419

     JOINT 16                 4.417                     4.417
  CENTROID 16                 4.417                     4.417

     JOINT 17                 6.601                     6.601
  CENTROID 17                 5.940                     5.940

     JOINT 18                 7.613                     7.613
  CENTROID 18                 5.831                     5.831

     JOINT 19                 8.026                     8.026
  CENTROID 19                 6.879                     6.879

     JOINT 20                 8.894                     8.894
  CENTROID 20                 7.802                     7.802

     JOINT 21                 8.026                     8.026
  CENTROID 21                 8.026                     8.026

     JOINT 22                 8.894                     8.894
  CENTROID 22                 8.894                     8.894

     JOINT 23                 9.245                     9.245
  CENTROID 23                 8.524                     8.524

     JOINT 24                10.170                    10.170
  CENTROID 24                 9.315                     9.315

     JOINT 25                 9.723                     9.723
  CENTROID 25                 0.000                     0.000

     JOINT 26                10.480                    10.480
  CENTROID 26                 0.000                     0.000

     JOINT 27                 0.000                     0.000
  CENTROID 27                 0.000                     0.000

     JOINT 28                 0.000                     0.000
  CENTROID 28                 0.000                     0.000
```

```
    JOINT 29            0.000              0.000
 CENTROID 29            0.000              0.000

    JOINT 30            0.000              0.000
 CENTROID 30            0.000              0.000

    JOINT 31            0.000              0.000
 CENTROID 31            0.000              0.000

    JOINT 32            0.000              0.000
 CENTROID 32            0.000              0.000

    JOINT 33            0.000              0.000
 CENTROID 33            0.000              0.000

    JOINT 34            0.000              0.000
 CENTROID 34            0.000              0.000

    JOINT 35            0.000              0.000
 CENTROID 35            0.000              0.000

    JOINT 36            0.000              0.000
 CENTROID 36            0.000              0.000
```

PART 3

SUMMATION OF TASK 1

```
                 MASS, CENTROID PRODUCTS, FOR EACH LINK
                      MASS    CENTROID DISPLACEMENT   WORK    CUMULATIVE WORK
                    (POUNDS)       (INCHES)          (LB-IN)      (LB-IN)

LINK  1               9.340          .265             2.471        2.471
LINK  2               0.000          .529             0.000        0.000
LINK  3              29.276         1.907            55.821       55.821
LINK  4               0.000         4.664             0.000        0.000
LINK  5               2.611         5.029            13.133       13.133
LINK  6               9.106         7.154            65.139       65.139
LINK  7               0.000         9.212             0.000        0.000
LINK  8               0.000         9.627             0.000        0.000
LINK  9               0.000         0.000             0.000        0.000
LINK 10               0.000         0.000             0.000        0.000
LINK 11               0.000         4.376             0.000        0.000
LINK 12               0.000         4.255             0.000        0.000
LINK 13               3.867         4.923            19.035       19.035
LINK 14               3.867         4.302            16.635       16.635
LINK 15               0.000         5.419             0.000        0.000
LINK 16               0.000         4.417             0.000        0.000
LINK 17               4.101         5.940            24.361       24.361
LINK 18               4.101         5.831            23.915       23.915
LINK 19               2.277         6.879            15.662       15.662
LINK 20               2.277         7.802            17.764       17.764
LINK 21               0.000         8.026             0.000        0.000
LINK 22               0.000         8.694             0.000        0.000
LINK 23               1.021         8.524             8.704        8.704
LINK 24               1.021         9.315             9.512        9.512
LINK 25               1.021         0.000             0.000        0.000
LINK 26               1.021         0.000             0.000        0.000
LINK 27               7.281         0.000             0.000        0.000
LINK 28               7.281         0.000             0.000        0.000
LINK 29              12.972         0.000             0.000        0.000
LINK 30              12.972         0.000             0.000        0.000
LINK 31               5.926         0.000             0.000        0.000
LINK 32               5.926         0.000             0.000        0.000
LINK 33               2.059         0.000             0.000        0.000
LINK 34               2.059         0.000             0.000        0.000
LINK 35               0.000         0.000             0.000        0.000
LINK 36               0.000         0.000             0.000        0.000
SUMMED TOTAL        131.3828      127.2893          272.1510
```

```
                              PART 3

                      SUMMATION OF TASK  1




           JOINT ANGULAR DEFLECTIONS (PSI)
            TASK DEFLECTION (DEGREES)   CUMULATIVE DEFLECTION (DEGREES)

 JOINT  1              0.000                     0.000
 JOINT  2              0.000                     0.000
 JOINT  3             -7.210                    -7.210
 JOINT  4              0.000                     0.000
 JOINT  5              0.000                     0.000
 JOINT  6              2.603                     2.603
 JOINT  7              0.000                     0.000
 JOINT  8              0.000                     0.000
 JOINT  9              0.000                     0.000
 JOINT 10              0.000                     0.000
 JOINT 11              0.000                     0.000
 JOINT 12              0.000                     0.000
 JOINT 13              0.000                     0.000
 JOINT 14              0.000                     0.000
 JOINT 15              0.000                     0.000
 JOINT 16              0.000                     0.000
 JOINT 17            -15.284                   -15.284

 JOINT 18             28.804                    28.804
 JOINT 19            -14.257                   -14.257
 JOINT 20             18.892                    18.892
 JOINT 21              0.000                     0.000
 JOINT 22              0.000                     0.000
 JOINT 23              0.000                     0.000
 JOINT 24              0.000                     0.000
 JOINT 25              0.000                     0.000
 JOINT 26              0.000                     0.000
 JOINT 27              0.000                     0.000
 JOINT 28              0.000                     0.000
 JOINT 29             61.835                    61.835
 JOINT 30            -61.835                   -61.835
 JOINT 31              0.000                     0.000
 JOINT 32              0.000                     0.000
 JOINT 33              0.000                     0.000
 JOINT 34              0.000                     0.000
 JOINT 35              0.000                     0.000
 JOINT 36              0.000                     0.000

  HEAD DEFLECTION     47.338                    47.338
  EYE DEFLECTION      52.098                    52.098
```

APPENDIX I

OVERLAY	SUBROUTINES USED
CGE	POOL*
INTRAN	ANGLET, SETUP, RØT3, TRANSF, DTPF, AFF, MAB, KØMPAR*
REACHA	PREANL, MINUM, RAND*, FUN1$^+$, FUN2$^+$, FUN3$^+$, FUN4$^+$, FUN5$^+$, FUN6$^+$, FUN7$^+$, REDEF
MAN1	RYTE, TASK, LINE, ROT3, POSE, TRANSF, DTPF, AFF, MAB$^{\otimes}$, LYNX, RAKE, SPRING (+FUN), SPRINX (+DER), POC (+PENF), POXC (+PENFX), PENLTY, TRAC, HBAD, REPLCE, CTERP, FTERP, RØ3$^{\diamond}$
INTERF	INSECT, DET2, DET3, DET4
SUMM	CMLØC
OUTGO	None

*System Subroutine

+Function subroutine

⊗With MATB, MABT entry points

⋄With entry point RØ3F

APPENDIX II

BLOCK COMMON NAMES IN EACH OVERLAY

APPENDIX II

OVERLAY	BLOCK COMMON USED
CGE	INTERF, TASKS, LINKS, STDPØS, CONTRL, ØUT, MAN, SUM, ITRANS, RØTATE, PROD, POINTS, FCON, INDEX, TRANS, IPØC, BDRY, PRØBLM, INØUT, KØNTRL, CIRCLE
INTRAN	INTERF, TASKS, LINKS, STDPØS, CONTRL, ØUT, SUM, ITRANS, RØTATE, PRØD, POINTS, FCØN, INDEX, TRANS, IPØC, BDRY, PROBLM, INØUT, KØNTRL, CIRCLE
REACHA	TASKS, LINKS, STDPØS, CONTRL, OUT, MAN
MAN1	STDPØS, MAN, ITRANS, ROTATE, PROD, PØINTS, FCØN, INDEX, TRANS, IPØC, BDRY, PRØBLM, INØUT, KØNTRL, CIRCLE, PØCTRA*, WDER*, RMINK*, EYE*, FUN*, KRAKE*, TRAP*, MUZZLE*, INTERP*, FANG*, ICØMM*, FTERP*
INTERF	INTERF, TASKS, LINKS, STDPØS, CONTRL, ØUT, MAN
SUMM	SUM, LINKS, STDPØS, ØUT, IPØC
OUTGO	INTERF, TASKS, LINKS, STDPØS, CØNTRL, ØUT, MAN, SUM

*Local to overlay

Appendix III

Variables In Block Common

Appendix III

Block Common	Variables	Length
(Global Blocks)		
BDRY	BL(42, BU(42), ACB(42)	126
CIRCLE	DR, PI, PII	3
CONTRL	KT1,KT2,KT3,KT4,KT5,KT6,KT7,KT8,KT9,KT10, KT11,KT12,KT13,KT14,KT15,KT16,KT17,KT18, KT19,KT20,KT21(20),KT22(20)	60
FCØN	CCØN(15),SCØN(15)	30
INDEX	IP,N,M,KØUNT,KKØUNT,LM	6
INØUT	PTI(15),PTF(15),STEPS	31
INTERF	NPL,NVERT(36),PDES(4,36), PPT(3,6,36),NCC	830
IPØC	IA,IB,IC,IJOIN,IUB,NUB,LA,LAL, LB,LJOIN,ISPRA(10),LBL,LLA(10), IH(8),IJP1	40
ITRANS	IQ(42),IPAR(42)	84
KONTRL	ISKIP,MAN,IPOSE,NSTEPS,NMJ,MAXMA, ICØN,NCASE,KPØS	9
LINKS	NL,LINKS(36),MASS(36),CNTLOC(36), LVOC(3,36),PCT(36),LN(36),OPCT(36), CPCT(36)	361
MAN	IREDEF,X3,Y3,Z3,INF,FROM,SWITCH,NSTEP	8
ØUT	BLANK,ØSERV,IM,DGCV,JTASK,IN,IN1,IN2, IN3	9
PØINTS	P(3,36),DP(3,42,36)	4644
PRØBLM	CØNST(100)	100
PROD	TP(3,3),DTP(3,3,42),TIP(3,3) DTIP(3,3,42),TRNSLT(36)	810

RØTATE	T(3,3,36),DT(3,9,36),F(2,3),JDER	1303
STDPØS	STDPØS(3,36),ANGLIM(6,36),R(3,36), RF(3,36),ANGLE1(3,36),ANGLE2(3,36)	756
SUM	CTD(36),CTMD(36),CWØRK(36), CDJA(36),CDI,CDHD	146
TASKS	NT,RHTPT(3,20),LHTPT(3,20),ETPT(3,20), TDUR(20),THØLD(20),TDES(7,20),RHØRT(3,20), LHØRT(3,20),	481
TRANS	ERR,FX,PXN,PK,SCALE,X(27),GX(27), PF(30),GSXTST,ERC	91

$23310_8 = 9928_{10}$

Block Common	Variables	Length
(Local to MAN1 Overlay)		
EYE	ALEPH(3),BETH(3),GIMEL(3),BETHN, BETHNS	11
FANG	H(30,30),A(30,30),B(30,30)	2700
FTERP	FI,FII,XI(30),XII(30),KILL	63
FUN	A(30),G(30)	60
ICØMM	NN,NNN,MM,MMM	4
INTERP	EP1,EP2,SIG(30),S(30),R	63
KRAKE	KCALL	1
MUZZLE	V(30),P(30),GV(30),PENX(30),PV(30,30) VLAMBD(30)	1050
PØCTRA	DRIGHT(3,15),DLEFT(3,15),PT(20)	110
RMINK	FV,PEN,ELACS,PK2,FY,FZ,GSX,GSZ,ETA, Z,Ø,FRAC,AZAHA,YHDEN,SIGY	15
TRAP	PX(30,30),PXNX(30),XLAMBD(30)	960
WDER	GW(27)	27
		$11710_8 = 5064_{10}$

Appendix IV

Definition of Variables

APPENDIX IV

VARIABLE	TYPE	DIMENSION	1st ENCOUNTER PROGRAM, SUBROUTINE	COMMON BLOCK	G
ARRAY	REAL	(100)	CGE,		
FROM	INTEGER		CGE,	MAN	
INF	INTEGER		CGE,	MAN	
IXX*	INTEGER		CGE,		
JTASK	INTEGER		CGE,	ØUT	
NT*	INTEGER		CGE,	TASKS	
PSEUD	REAL		CGE,		
SWITCH	INTEGER		CGE,	MAN	
ZATRIX	REAL	(3)	CGE,		
ANGLE1	REAL	(3,36)	INTRAN,	STDPØS	
ANGLIM	REAL	(6,36)	INTRAN,	STDPØS	
BLANK	REAL		INTRAN,	OUT	
CDHD	REAL		INTRAN,	SUM	
CDI	REAL		INTRAN,	SUM	
CDJA	REAL	(36)	INTRAN,	SUM	
CNTLØC	REAL	(36)	INTRAN,	LINKS	
COMENT*	REAL	(24)	INTRAN,		

* Denotes Card or Tape

APPENDIX IV

ER	COMMON BLOCK	LOCAL OR GLOBAL	DEFINITION
		L	Storage array used in Subroutine POOL
	MAN	G	FROM = {0 Program MAN1 called after INTERF 1 Program MAN1 called after REACHA
	MAN	G	INF = {0 Task is feasible 1 Task infeasible
		L	Used to read EØF to get abnormal exit with file and
	ØUT	G	Stores current task number
	TASKS	G	Stores total number of tasks in task sequence
		L	References the Hollerith word "CGE"
	MAN	G	Switch = {0 No visual interference, continue 1 Program MAN1 recalled
		L	Stores logical file names, used in Subroutine POOL
	STDPØS	G	References Euler angle values at each joint of BOEM Angle1(I,J): I = TYPE of angle (θ,φ,ψ) J = Joint
	STDPØS	G	References lower and upper angles bounds on joint ANGLIM(I,J): I = 2i Upper Bound 2i-1 Lower Bound i = 1,2,3; = Type of angle (θ,φ,ψ) J = Joint Numb
	OUT	G	Stores a 10 character blank word for the output ove
	SUM	G	Stores the cumulative head deflection angle
	SUM	G	Stores the cumulative eye deflection angles
	SUM	G	Stores the cumulative joint twist angle for each jo
	LINKS	G	Stores the relative centroid distance from a link e for each link
		L	References a description of the evaluation run for lay

* Denotes Card or Tape Input Variable

DEFINITION

Storage array used in Subroutine POOL

$$\text{FROM} = \begin{cases} 0 & \text{Program MAN1 called after INTERF} \\ 1 & \text{Program MAN1 called after REACHA} \end{cases}$$

$$\text{INF} = \begin{cases} 0 & \text{Task is feasible} \\ 1 & \text{Task infeasible} \end{cases}$$

Used to read EØF to get abnormal exit with file and core dumps

Stores current task number

Stores total number of tasks in task sequence

References the Hollerith word "CGE"

$$\text{Switch} = \begin{cases} 0 & \text{No visual interference, continue} \\ 1 & \text{Program MAN1 recalled} \end{cases}$$

Stores logical file names, used in Subroutine POOL

References Euler angle values at each joint of BOEMAN-I,

Angle1(I,J): I = TYPE of angle (θ, φ, ψ) J = Joint Number

References lower and upper angles bounds on joint

ANGLIM(I,J): I = 2i Upper Bound

2i-1 Lower Bound

i = 1,2,3; = Type of angle (θ, φ, ψ) J = Joint Number

Stores a 10 character blank word for the output overlay

Stores the cumulative head deflection angle

Stores the cumulative eye deflection angles

Stores the cumulative joint twist angle for each joint

Stores the relative centroid distance from a link endpoint for each link

References a description of the evaluation run for output overlay

3

CØNST*	REAL	(100)	INTRAN,	PRØBLM
CTD	REAL	(36)	INTRAN,	SUM
CTMD	REAL	(36)	INTRAN,	SUM
CWØRK	REAL	(36)	INTRAN,	SUM
DGCV	REAL		INTRAN,	ØUT
DUM1*				
DUM2*				
DUM3*	REAL		INTRAN,	
DUM4*				
ERC*	REAL		INTRAN,	TRANS
ERR*	REAL		INTRAN,	TRANS
ETC*	REAL	(20)	INTRAN,	
ETPT	REAL	(3,20)	INTRAN,	TASKS
IA	INTEGER		INTRAN,	IPØC
IB	INTEGER		INTRAN,	ZPOC
IC	INTEGER		INTRAN,	IPOC
IM	INTEGER		INTRAN,	OUT
IP*	INTEGER		INTRAN,	INDEX
IPOSE*	INTEGER		INTRAN,	KONTRL
ISKIP*	INTEGER		INTRAN,	KONTRL
IUB	INTEGER		INTRAN,	IPOC

* Denotes card or tap

APPENDIX IV

AN,	PRØBLM	G	A set of weighting constants for penalty functi Euler angles for objective function in MAN1
AN,	SUM	G	Stores the cumulative displacement of each join
AN,	SUM	G	Stores cumulative centroid displacement of each
AN,	SUM	G	Stores cumulative work done for each link
AN,	ØUT	G	$= \frac{\pi}{180}$; conversion factor for degrees and radian
AN,		L	Stores superfluous descriptions of retrieved da
AN,	TRANS	G	Used in MAN1; Allowed error in each equality co
AN,	TRANS	G	Used in MAN1; Allowed minimization error for LY
AN,		L	Control code to be viewed by the eye midpoint f
AN,	TASKS	G	Control point (corresponding to code) to be vie eye midpoint, ETPT(I,J): I = type of Euclidian coord (x,y,z)
AN,	IPØC	G	= 24; Used in MAN1; Index of right arm terminal
AN,	ZPOC	G	= 23; Used in MAN1; Index of left arm terminal j
AN,	IPOC	G	= 7 ; Used in MAN1; index of eye midpoint
AN,	OUT	G	= 12; Contains intermediate output file no.
AN,	INDEX	G	Contains MAN1 error output option value (=1,Yes
AN,	KONTRL	G	Used in MAN1; specifies whether BOEMAN's positio lated from input angles.
AN,	KONTRL	G	Used in MAN1; specifies whether first position be bypassed.
AN,	IPOC	G	= 10; Used in MAN1; number of links in spine - r

* Denotes card or tape input variable

A set of weighting constants for penalty function and preferred Euler angles for objective function in MAN1

Stores the cumulative displacement of each joint

Stores cumulative centroid displacement of each link

Stores cumulative work done for each link

= $\frac{\pi}{180}$; conversion factor for degrees and radians

Stores superfluous descriptions of retrieved data sets

Used in MAN1; Allowed error in each equality constraint.

Used in MAN1; Allowed minimization error for LYNX

Control code to be viewed by the eye midpoint for each task

Control point (corresponding to code) to be viewed by the eye midpoint,
ETPT(I,J): I = type of Euclidian coord (x,y,z) J = Task Number.

= 24; Used in MAN1; Index of right arm terminal joint

= 23; Used in MAN1; Index of left arm terminal joint

= 7 ; Used in MAN1; index of eye midpoint

= 12; Contains intermediate output file no.

Contains MAN1 error output option value (=1,Yes)

Used in MAN1; specifies whether BOEMAN's position is to be calculated from input angles.

Used in MAN1; specifies whether first position optimization is to be bypassed.

= 10; Used in MAN1; number of links in spine - right arm system

3

KOM	INTEGER	INTRAN,	
KT1*	INTEGER	INTRAN,	CØNTRL
KT2*	INTEGER	INTRAN,	CØNTRL
KT3*	INTEGER	INTRAN,	CØNTRL
KT4*	INTEGER	INTRAN,	CØNTRL
KT5*	INTEGER	INTRAN,	CØNTRL
KT6*	INTEGER	INTRAN,	CØNTRL
KT7*	INTEGER	INTRAN,	CØNTRL
KT8*	INTEGER	INTRAN,	CØNTRL
KT9*	INTEGER	INTRAN,	CØNTRL
KT10*	INTEGER	INTRAN,	CØNTRL
KT11	INTEGER	INTRAN,	CØNTRL
KT12*	INTEGER	INTRAN,	CØNTRL
KT13*	INTEGER	INTRAN,	CØNTRL
KT14	INTEGER	INTRAN,	CØNTRL
KT15*	INTEGER	INTRAN,	CØNTRL
KT16	INTEGER	INTRAN,	CØNTRL
KT17*	INTEGER	INTRAN,	CONTRL

*Denotes

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INTRAN,		L	= 0 Task control code matches dictionar 1 No match (output variable from subr
INTRAN,	CØNTRL	G	= 0 Input data to be printed out 1 Input data not to be printed
INTRAN,	CØNTRL	G	= 0 Do not print link dimensions 1 Print out link dimensions (Outgo)
INTRAN,	CØNTRL	G	= 0 Do not print task information 1 Print task information (Outgo)
INTRAN,	CØNTRL	G	= 0 Do not print standard angular posit 1 Print standard angular position (O
INTRAN,	CØNTRL	G	= 0 Do not print joint angle limits 1 Print joint angle limits (O
INTRAN,	CØNTRL	G	= 0 Do not print cockpit geometry or co 1 Print cockpit geometry and codes (
INTRAN,	CØNTRL	G	= 0 Standard link survey used 1 Non-standard link survey used (
INTRAN,	CØNTRL	G	= 0 Do not print standard position join 1 Print standard position joint coord
INTRAN,	CØNTRL	G	= 0 Do not print (SRP) control location 1 print (SRP) control locations (
INTRAN,	CØNTRL	G	= 0 Extended hand position tested 1 Clenched hand position tested (
INTRAN,	CØNTRL	G	= 0 Task initially feasible 1 Task redefined (
INTRAN,	CØNTRL	G	= 0 Do not print reach analysis output 1 Print reach analysis output (
INTRAN,	CØNTRL	G	Not used currently
INTRAN,	CØNTRL	G	= 0 No visual interference 1 Visual interference exists
INTRAN,	CØNTRL	G	= 0 Determine new position correspondin 1 Do not calculate new position
INTRAN,	CØNTRL	G	= 0 No physical interference 1 Physical interference exists
INTRAN,	CONTRL	G	

*Denotes card or tape input variable

$= \begin{cases} 0 & \text{Task control code matches dictionary entry} \\ 1 & \text{No match (output variable from subroutine KØMPAR)} \end{cases}$

$= \begin{cases} 0 & \text{Input data to be printed out} \\ 1 & \text{Input data not to be printed} \end{cases}$

$= \begin{cases} 0 & \text{Do not print link dimensions} \\ 1 & \text{Print out link dimensions (Outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print task information} \\ 1 & \text{Print task information (Outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print standard angular position} \\ 1 & \text{Print standard angular position (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print joint angle limits} \\ 1 & \text{Print joint angle limits (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print cockpit geometry or codes} \\ 1 & \text{Print cockpit geometry and codes (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Standard link survey used} \\ 1 & \text{Non-standard link survey used (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print standard position joint coordinates} \\ 1 & \text{Print standard position joint coordinates (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print (SRP) control locations} \\ 1 & \text{print (SRP) control locations (outgo)} \end{cases}$

$= \begin{cases} 0 & \text{Extended hand position tested} \\ 1 & \text{Clenched hand position tested (reacha)} \end{cases}$

$= \begin{cases} 0 & \text{Task initially feasible} \\ 1 & \text{Task redefined (reacha)} \end{cases}$

$= \begin{cases} 0 & \text{Do not print reach analysis output} \\ 1 & \text{Print reach analysis output (outgo)} \end{cases}$

Not used currently

$= \begin{cases} 0 & \text{No visual interference} \\ 1 & \text{Visual interference exists} \end{cases}$

$= \begin{cases} 0 & \text{Determine new position corresponding to new line of sight} \\ 1 & \text{Do not calculate new position} \end{cases}$

$= \begin{cases} 0 & \text{No physical interference} \\ 1 & \text{Physical interference exists} \end{cases}$

e input variable

3

KT18*	INTEGER		INTRAN,	CØNTRL
KT19*	INTEGER		INTRAN,	CØNTRL
KT20*	INTEGER		INTRAN,	CONTRL
LA	INTEGER		INTRAN,	IPOC
LB	INTEGER		INTRAN,	IPOC
LHORT*	REAL	(3,20)	INTRAN,	TASKS
LHTC*	REAL	(20)	INTRAN,	
LHTPT	REAL	(3,20)	INTRAN,	TASKS
LINKS	REAL	(36)	INTRAN,	LINKS
LMEAN*	REAL	(36)	INTRAN,	
LN*	INTEGER	(36)	INTRAN,	LINKS
LSTD*	REAL	(36)	INTRAN,	
LFTY	REAL		INTRAN,	
LFTZ	REAL		INTRAN,	
LVØC	INTEGER	(3,36)	INTRAN,	LINKS
MAN*	INTEGER		INTRAN,	KØNTRL
MASS	REAL	(36)	INTRAN,	LINKS
MCPCT*	REAL	(36)	INTRAN,	LINKS
MMEAN*	REAL	(36)	INTRAN,	
MSTD*	REAL	(36)	INTRAN,	

* Denotes card

APPENDIX IV

N,	CØNTRL	G	Not Used currently
N,	CØNTRL	G	Not Used Currently
N,	CONTRL	G	Not Used Currently
N,	IPOC	G	= 13; Used in MAN1;total number of angles in spi
N,	IPOC	G	= 22; Used in MAN1;LA + number of angles in left
N,	TASKS	G	Task defined left hand orientation angles LHORT(J = TYPE of angle. (θ, φ, ψ)) J = Task No.
N,		L	Task defined control code for left hand,each tas
N,	TASKS	G	Control point for left hand, each task LHTPT(I,J I = coordinates (x,y,z) J = task number.
N,	LINKS	G	Stores BOEMANS link lengths,each link
N,		L	Contains link length means, each link
N,	LINKS	G	Contains link numbers, each link
N,		L	Contains link length standard deviations, each l
N,		L	Contains differences in y coordinate of seat and reference points
N,		L	Contains difference in z coordinate of seat and reference points
N,	LINKS	G	Contains 28 character link name, each link I = 1,3;10 characters each; J = link no.
N,	KØNTRL	G	= { 0 If no output from MAN1 is desired 1 otherwise
N,	LINKS	G	Stores BOEMANS link mass, each link
N,	LINKS	G	References % distance of centroid from proxima
N,		L	Contains means of link mass, per link
N,		L	Contains link mass standard deviations, per link

* Denotes card or tape input variable

sed currently

sed Currently

sed Currently

Used in MAN1; total number of angles in spine and right arm

Used in MAN1; LA + number of angles in left arm

defined left hand orientation angles LHORT(I,J);
YPE of angle. (θ, φ, ψ) J = Task No.

defined control code for left hand, each task

ol point for left hand, each task LHTPT(I,J)
oordinates (x,y,z) J = task number.

s BOEMANS link lengths, each link

ins link length means, each link

ins link numbers, each link

ins link length standard deviations, each link

ins differences in y coordinate of seat and eye
ence points

ins difference in z coordinate of seat and eye
ence points

ins 28 character link name, each link
,3; 10 characters each; J = link no.
If no output from MAN1 is desired
otherwise

s BOEMANS link mass, each link

ences % distance of centroid from proximal end

ins means of link mass, per link

ins link mass standard deviations, per link

APPENDIX IV

NAF*	INTEGER		INTRAN,	
NCC*	INTEGER		INTRAN,	INTERF
NCF*	INTEGER		INTRAN,	
NL*	INTEGER		INTRAN,	LINKS
NLF*	INTEGER		INTRAN,	
NMJ*	INTEGER		INTRAN,	KONTRL
NNF*	INTEGER		INTRAN,	
NØF*	INTEGER		INTRAN,	
NPCT	INTEGER		INTRAN,	
NPF*	INTEGER		INTRAN,	
NPL*	INTEGER		INTRAN,	INTERF
NSF*	INTEGER		INTRAN,	
NSTEPS*	INTEGER		INTRAN,	KØNTRL
NT*	INTEGER		INTRAN,	TASKS
NTF*	INTEGER		INTRAN,	
NUB	INTEGER		INTRAN,	IPØC
NVERT	INTEGER	(36)	INTRAN,	INTERF
NVT*	INTEGER		INTRAN,	
OPCT*	REAL	(36)	INTRAN,	LINKS
OSERV*	REAL		INTRAN,	
P	REAL	(3,36)	INTRAN,	POINTS
PCT*	REAL	(36)	INTRAN,	LINKS
PDES*	REAL	(4,36)	INTRAN,	INTERF
PPT*	REAL	(3,6,36)	INTRAN,	INTERF

* Denotes car

APPENDIX IV

RAN,		L	= 11; File Number for joint angular limits dat
RAN,	INTERF	G	Number of control codes
RAN,		L	= 11; File Number for control code data
RAN,	LINKS	G	Number of links of BOEMAN-I
RAN,		L	= 11 File Number for link data
RAN,	KONTRL	G	Number of moveable joints
RAN,		L	= 11 File Number for normal table distribution
RAN,		L	= 11 Not currently used
RAN,		L	References each link percentile PCT (I)
RAN,		L	= 11 File Number for cockpit planes data
RAN,	INTERF	G	Number of cockpit planes
RAN,		L	= 11 File Number for standard position data
RAN,	KØNTRL	G	Size of each step in a task
RAN,	TASKS	G	Number of tasks
RAN,		L	= 11 File Number for task data
RAN,	IPØC	G	Number of joints in the spine head system
RAN,	INTERF	G	Number of vertices of each cockpit planes
RAN,		L	Number of vertices of a cockpit plane
RAN,	LINKS	G	Percentiles for non-standard survey
RAN,		L	Non-standard survey name (up to 10 characters)
RAN,	POINTS	G	Joint position array in Euclidean coordinates
RAN,	LINKS	G	Percentile values per link Ᵽ(I,J), I=1,3 (x,y, J = 1, No. of joints
RAN,	INTERF	G	40 character cockpit plane identifiers
RAN,	INTERF	G	Cockpit plane vertex coordinates PPT(I,J,K) J J=1, no. vertices, K=1, no. of planes

* Denotes card or tape input variable

= 11; File Number for joint angular limits data

Number of control codes

= 11; File Number for control code data

Number of links of BOEMAN-I

= 11 File Number for link data

Number of moveable joints

= 11 File Number for normal table distribution

= 11 Not currently used

References each link percentile PCT (I)

= 11 File Number for cockpit planes data

Number of cockpit planes

= 11 File Number for standard position data

Size of each step in a task

Number of tasks

= 11 File Number for task data

Number of joints in the spine head system

Number of vertices of each cockpit planes

Number of vertices of a cockpit plane

Percentiles for non-standard survey

Non-standard survey name (up to 10 characters)

Joint position array in Euclidean coordinates

Percentile values per link P(I,J), I=1,3 (x,y,z)
J = 1, No. of joints

40 character cockpit plane identifiers

Cockpit plane vertex coordinates PPT(I,J,K) J=1,3 (x,y,z)
J=1, no. vertices, K=1, no. of planes

ıle

Q	REAL		INTRAN,	
R	REAL	(3,36)	INTRAN,	STDPØS
RF	REAL	(3,36)	INTRAN,	STDPØS
RHØRT*	REAL	(3,20)	INTRAN,	TASKS
RHTC*	REAL	(50)	INTRAN,	
RHTPT	REAL	(3,20)	INTRAN,	TASKS
SCALE*	REAL		INTRAN,	TRANS
SP	REAL	(3)	INTRAN,	
STDPØS*	REAL	(3,36)	INTRAN,	STDPØS
TASKNØ*	INTEGER	(50)	INTRAN,	
TCLØC	REAL	(3,91)	INTRAN,	
TCVØC	REAL	(91)	INTRAN,	
TDES	REAL	(7,20)	INTRAN,	TASKS
TDUR	REAL	(20)	INTRAN,	TASKS
THØLD	REAL	(20)	INTRAN,	TASKS
U	REAL	(51)	INTRAN,	

* Denotes card o

APPENDIX IV

INTRAN,		L	Denotes the normal deviate value correspondi link percentile
INTRAN,	STDPØS	G	Initial joint position array in Euclidean co (same as P)
INTRAN,	STDPØS	G	Final position array at end of task in Eucli
INTRAN,	TASKS	G	Task defined right hand orientation angles RHØRT(I,J) I=type of angle (θ,φ,ψ,); J=tas
INTRAN,		L	Task defined control code for right hand, ea
INTRAN,	TASKS	G	Control location for right hand, each task RHTPT(I,J) I=coordinates (x,y,z) J=task numb
INTRAN,	TRANS	G	Penalty coefficient scale factor
INTRAN,		L	Lumbar joint coordinates with respect to eye
INTRAN,	STDPØS	G	Standard angular position, each joint
INTRAN,		L	Task number of task sequence
INTRAN,		L	Task defined control locations TCLØC(I,J) I=(x,y,z) coordinates, J=task num
INTRAN,		L	10 character cockpit control codes
INTRAN,	TASKS	G	70 character task description, each task
INTRAN,	TASKS	G	Task duration in seconds, each task
INTRAN,	TASKS	G	Task hold time in seconds, each task
INTRAN,		L	Normal deviate values (positive half of table

* Denotes card or tape input variable

ɜnotes the normal deviate value corresponding to the
ɪnk percentile

ɔitial joint position array in Euclidean coordinates
ɜame as P)

ɪnal position array at end of task in Euclidean coordinates

ɪsk defined right hand orientation angles
IØRT(I,J) I=type of angle (θ, φ, ψ,); J=task number

ɪsk defined control code for right hand, each task

ɔntrol location for right hand, each task
ΙTPT(I,J) I=coordinates (x,y,z) J=task number

ɜnalty coefficient scale factor

ɪmbar joint coordinates with respect to eye reference point

:andard angular position, each joint

ɪsk number of task sequence

ɪsk defined control locations
:LØC(I,J) I=(x,y,z) coordinates, J=task number

) character cockpit control codes

) character task description, each task

ɪsk duration in seconds, each task

ɪsk hold time in seconds, each task

ɔrmal deviate values (positive half of table)

3

Appendix V

Storage and Retrieval Program and Subroutine Descriptions

Appendix V

Storage and Retrieval Subroutines

Program CAPSIS

Subroutines Used:

INITMF
SAVTBS
NVNTRY
LSTSTS
DFST
SVTBS
IØRC
TØC
KMPVLW
KWDS
RECUT2
MFWØRK
NVNTR
GTST
DPØUT
DPIN
TØXIC

Program RAPSIS

Subroutines Used:

NVNTRY
LSTSTS
GETSET
DFST
SVTBS
IØRC
TØC
KMPVLW
KWDS
RECUT2
MFWØRK
NVNTR
GTST
DPØUT
DPIN
TØXIC

Program CAPSIS

Program CAPSIS is the creation section of the Storage and Retrieval program. The data pool tape is created by first reading a card specifying the number of data sets to be read from the input file. Refer to the usage section (4.1) for the data set formats for various types of data. Each data set read is delimited by two cards. The first specifies the set name, and the second, specifies the end of the data. The data pool tape is created on file BPØØL.

SUBROUTINES CALLED are: INITMF, SAVTBS, NVNTRY, LSTSTS

Figure 10 shows the Program CAPSIS flow diagram.

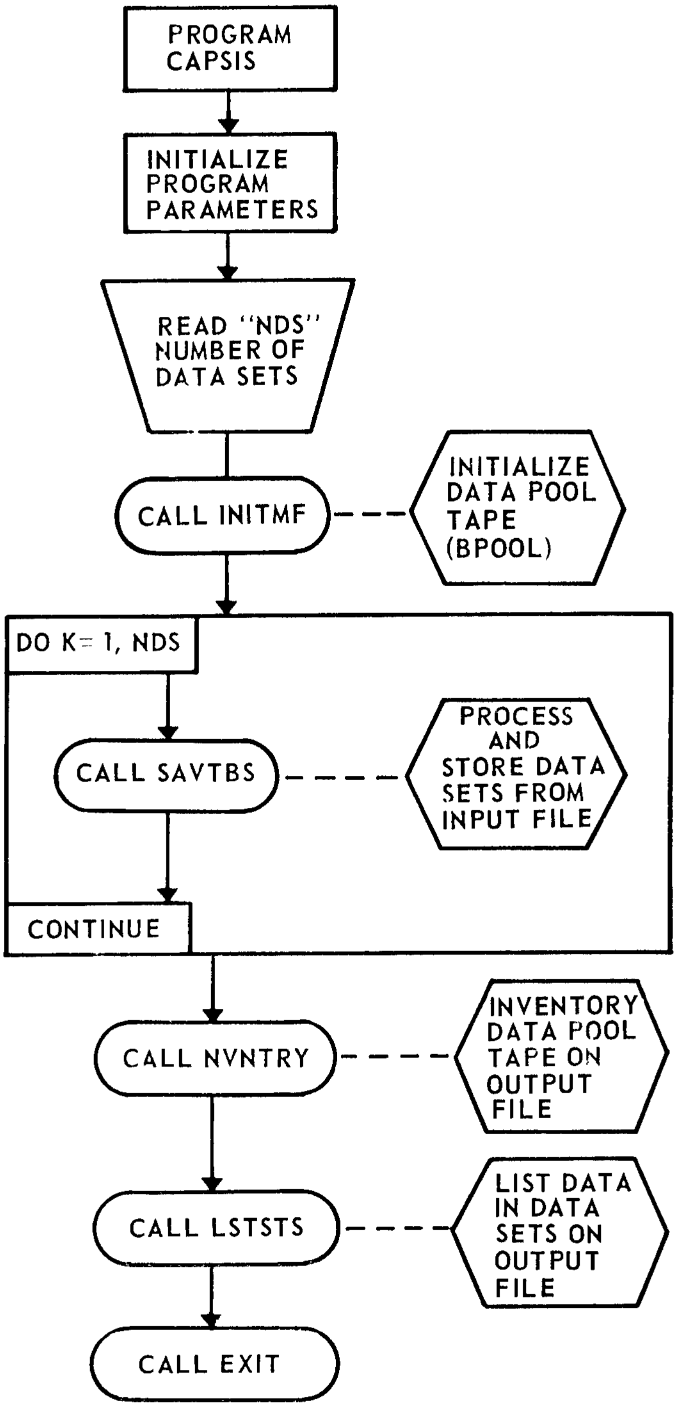

PROGRAM CAPSIS
INITIALIZE PROGRAM PARAMETERS
READ "NDS" NUMBER OF DATA SETS
CALL INITMF
INITIALIZE DATA POOL TAPE (BPOOL)
DO K= 1, NDS
CALL SAVTBS
PROCESS AND STORE DATA SETS FROM INPUT FILE
CONTINUE
CALL NVNTRY
INVENTORY DATA POOL TAPE ON OUTPUT FILE
CALL LSTSTS
LIST DATA IN DATA SETS ON OUTPUT FILE
CALL EXIT

Figure 10. Program CAPSIS—Flow Diagram

Program RAPSIS

Program RAPSIS is the retrieval section of the Storage and Retrieval program. Data sets are retrieved from the data pool tape by reading a card specifying the total number of sets to be retrieved and then reading a card specifying the data set name for each set requested. The data pool tape must be mounted on file BPØØL and the output tape on which the retrieved data are stored is on file WØRK. The order of the sets retrieved is established by the order in which the data set names were read.

SUBROUTINES CALLED are: GETSET, NVNTRY, and LSTSTS.

Figure 11 shows the Program RAPSIS flow diagram.

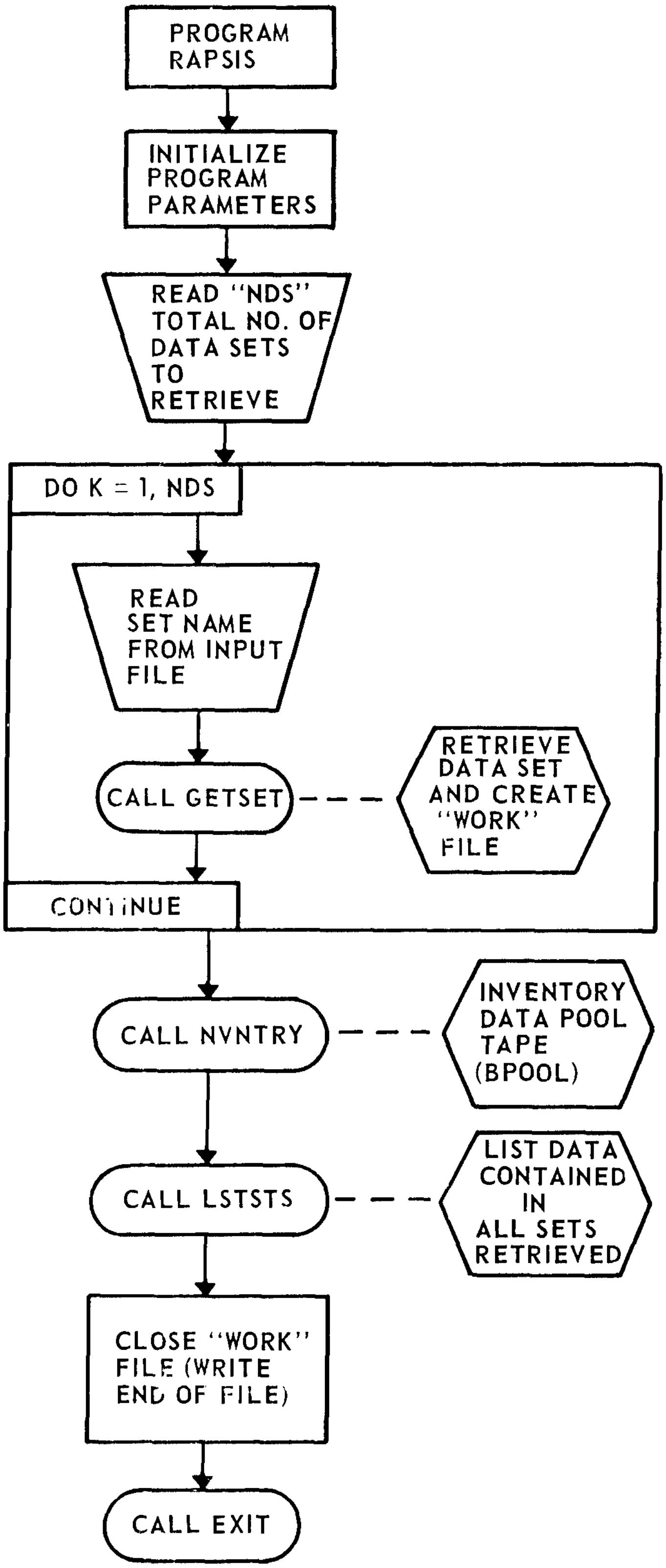

PROGRAM RAPSIS
INITIALIZE PROGRAM PARAMETERS
READ "NDS" TOTAL NO. OF DATA SETS TO RETRIEVE
DO K = 1, NDS
READ SET NAME FROM INPUT FILE
CALL GETSET
RETRIEVE DATA SET AND CREATE "WORK" FILE
CONTINUE
CALL NVNTRY
INVENTORY DATA POOL TAPE (BPOOL)
CALL LSTSTS
LIST DATA CONTAINED IN ALL SETS RETRIEVED
CLOSE "WORK" FILE (WRITE END OF FILE)
CALL EXIT

Figure 11. Program RAPSIS–Flow Diagram

Subroutine INITMF

Subroutine INITMF is called to initialize parameter when creating a data pool tape.

No Subroutines are called.

Subroutine DEFSET

This subroutine is not used in the present program configuration, but maybe utilized in later development of storage and retrieval.

Subroutines Called are: DPIN, TØC, DFST, TØCØØC, and DPØUT.

Subroutine REMSET

This subroutine is not used in the present program configuration, but maybe utilized in later development of a more sophisticated Storage and Retrieval system.

Subroutine Called are: DPIN, TØC, RMST, TØCØØC, and DPØUT.

Subroutine DFST

This subroutine is not used in the present program.

The subroutine called is: IØRC.

Subroutine RMST

This subroutine is not used in the present program.

The subroutine called is: IØRC.

Subroutine GETSET

Subroutine GETSET controls the retrieval processing of specified data sets to the user file WØRK. That is, the contexts of the data set specified is retrieved from File BPØØL and restored on user file WØRK.

Subroutine CAlled are: GTST, DPIN, TØXIC, and DPØUT

Subroutine GTST

Subroutine GTST is called from GETSET and performs the retrieval of particular data sets. After the set name has been read, GTST searches a table of data set names and retrieves the set from the pool. It is then written on the user WØRK file.

Subroutine Called are: KMPVLW, and KWDS.

Subroutine SVTBS

Subroutine SVTBS is called from program SAVTBS and performs the addition of data sets to the data pool tape. The data set cards are read, the names processed, and the data is written onto tape. The program checks all input set names for uniqueness.

Subroutine Called are: MFWØRK, DFST, and TØC.

Subroutine SAVTBS

Subroutine SAVTBS control the addition of the data sets to the data pool.

Subroutine Called are: DPIN, SVTBS, and DPØUT

Subroutine REMTAB

This subroutine is not used in present program configuration.

Subroutine Called are: INITMF, DPIN, RECØUT, TØC, RMST, MFWØRK, SVTBS, and DPØUT

Subroutine IØRC

Subroutine IØRC is called from DPST.

Subroutine NVNTRY

Subroutine NVNTRY provides an inventory of the data pool tape, listing all the set names, their location and length on the tape. This is written on the output file for later printing.

Subroutines called are: DPIN, TØXIC, MFWØRK, and DPØUT.

Subroutine LSTSTS

Subroutine LSTSTS provides a listing of the data contained in all the data sets stored on the data pool tape. This is written on the output file for later printing.

Subroutines called are: DPIN, DPØUT, TØXIC, GTST, and MFWØRK.

Subroutine MFWØRK

This subroutine is called from SVTBS for adding data sets, called from NVNTRY to obtain a file summary, and also from LSTSTS for full list of data.

(System) Subroutines KØMSTR, STRMØV

Two subroutines used by Storage and Retrieval programs are machine oriented so that equivalent subroutines must be written on what ever machine is used.

These routines are:

1. KØMSTR - Function compares two strings of characters

I = KOMSTR (S1,K1,N,S2,K2)

I = -1	String 1	<	String 2
0	"	=	"
1	"	>	"

S1, S2 - Arrays containing strings to compare

K1, K2 - Integer stating location in S1, S2 of 1st character to compare

N - Number of characters.

2. STRMØV - Moves a string of characters from one array to another.

Call STRMØV (S1,C1,N,S2,C2)

S1 - Array to be moved

S2 - Receiving array

C1 - Integer specifying position of first character to be moved relative to first position of array

N - Number of characters to be moved

C2 - Integer specifying position of 1st character in S2 which is to receive characters from S1

APPENDIX VI

CGE PROGRAM AND SUBROUTINE DESCRIPTIONS

SUBROUTINE POOL (A,B,C)

Program CGE calls a system routine providing for file sharing in the buffer. The calling sequence is CALL POOL (A,B,C) where:

A = An array consisting of logical file names (of size "B") (Input)

B = Number of binary files to be shared in the buffer minus one (Input)

C = A local storage array for the subroutine (of size 100)

A more detailed description of the system routine POOL may be found in References (1) and (2).

PROGRAM INTRAN

This program stores all input necessary for the evaluation whether it be user specified data on punched cards or Anthropometric or Cockpit data on magnetic tape. In each case, data is read into memory from the card reader and the retrieval tape. These data are written on an intermediate output file after being transformed. All of these files are declared in the main overlay (PROGRAM CGE). The program calls both a system routine and subroutine ANGLET (see below) which calls the remainder of the subroutines of this program.

SUBROUTINE ANGLET

The purpose of SUBROUTINE ANGLET is to calculate the initial joint locations of BOEMAN-I in the standard angular position, to initialize the palm locations and orientations, to store sine and cosines of fixed angles of joints, and to initialize the variable angles and the associated rotation matrices

Input variables required by ANGLET include:

N* = NL = number of links

(TRNSLT(I)) = LINKS(I) = link lengths, I = 1, NL

(ANG(I,J)) = ANGLIM(I,J) = angular limit on angle I,

I = 1, 3, 5 (Minimum θ, φ, ψ)
2, 4, 6 at joint J, J = 1, NL
(maximum θ, φ, ψ)

* Near the end of the routine, N is reset to the number of variable angles.

(SPOS(I,J)) = STDPOS(I,J) = angular value for θ, φ, ψ (I = 1, 3) at joint J, J=1, NL

Output variables calculated by ANGLET include

ISPRA(I) = array of joint numbers for right arm and spine systems

ILA(I) = array of joint numbers for left arm system

IH(I) = array of joint numbers for head system

IRL(I) = array of joint numbers for right leg system

ILL(I) = array of joint numbers for left leg system

WR(I) = variable joint angle initial values (in radians) I = 1, K1 (number of variable angles)

CR(I) = constant angles of joints I = 1, K2 (number of constant angles)

SCON(I) = sin (CR(I))

CCON(I) = cos (CR(I))

P(I,J) = R(I,J) = initial joint locations I = 1,3 (coordinate x, y, z) J = joint number

N = number of variable joint angles

X(I) = initial values of variable joint angles, I = 1, N (used in MAN1)

PTI(J) = initial palm position (J = 1, 3), (J = 7, 9) and orientation (J = 4, 6), (J = 10, 12) right and left hands respectively and eye viewing point (J = 13, 15)

This subroutine (ANGLET) calls subroutines SETUP and TRANSF each time a link system is to be referenced. A joint angle designation table, given below, describes each of the link systems, their numbering system, and whether each angle of any joint is a variable or a constant.

SUBROUTINE SETUP

The basic function of subroutine SETUP is to sort the ANGLIM(I,J)(=ANG(I,J)) array into three categories

(1) a variable angle in a joint (θ, φ, or ψ)

(2) a constant angle in a joint having at least one other variable angle

(3) a constant angle in a joint having all constant angles

ANGLIM(I,J) gives the lower and upper bounds of each angle in each joint. If an angle is constant, both of these bounds have the same value.

JOINT ANGLE DESIGNATION TABLE

SPINE SYSTEM

JOINT NO./ LINK NO.	JOINT NAME/ LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
1	LUMBAR	1 (THETA)	1 (PHI) 2 (PSI)	--
2	DUMMY THORACIC			1 (THETA) 2 (PHI) 3 (PSI)
3	THORACIC	2 (THETA) 3 (PHI) 4 (PSI)		--

HEAD SYSTEM

JOINT NO./ LINK NO.	JOINT NAME/ LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
4	VERTICAL NECK	--	--	25 (THETA) 26 (PHI) 27 (PSI)
5	HORIZONTAL NECK	--	--	28 (THETA) 29 (PHI) 30 (PSI)
6	VERTICAL	23 (THETA) 24 (PHI) 25 (PSI)	--	--
7	HORIZONTAL HEAD	--	--	31 (THETA) 32 (PHI) 33 (PSI)
8	EYE MIDPOINT VECTOR	26 (THETA) 27 (PHI)	11 (PSI)	--
9	HEAD-LEFT EYE			31 (THETA) 32 (PHI) 33 (PSI)
10	HEAD-RIGHT EYE			31 (THETA) 32 (PHI) 33 (PSI)

RIGHT ARM SYSTEM

JOINT NO./ LINK NO.	JOINT NAME LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
12	INTERCLAVICULAR	--	--	4 (THETA) 5 (PHI) 6 (PSI)
14	CLAVICLE	5 (THETA) 6 (PHI)	3 (PSI)	--
16	DUMMY SHOULDER	--	--	7 (THETA) 8 (PHI) 9 (PSI)
18	HUMERAL	7 (THETA) 8 (PHI) 9 (PSI)	--	--
20	RADIAL	10 (THETA) 11 (PSI)	4 (PHI)	--
22	DUMMY WRIST	--	--	10 (THETA) 11 (PHI) 12 (PSI)
24	PALM (HAND EXTENDED)	12 (THETA) 13 (PHI)	5 (PSI)	
26	PALM (HAND CLENCHED)	12 (THETA) 13 (PHI)	6 (PSI)	

LEFT ARM SYSTEM

JOINT NO./ LINK NO.	JOINT NAME/ LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
11	INTERCLAVICULAR	--	--	13 (THETA) 14 (PHI) 15 (PSI)
13	CLAVICLE	14 (THETA) 15 (PHI)	7 (PSI)	16 (THETA) 17 (PHI) 18 (PSI)
15	DUMMY SHOULDER	--	--	19 (THETA) 20 (PHI) 21 (PSI)
17	HUMERAL	16 (THETA) 17 (PHI) 18 (PSI)	--	--
19	RADIAL	19 (THETA) 20 (PSI)	8 (PHI)	--
21	DUMMY WRIST	--	--	22 (THETA) 23 (PHI) 24 (PSI)
23	HAND (HAND EXTENDED)	21 (THETA) 22 (PHI)	9 (PSI)	--
25	HAND (HAND CLENCHED)	21 (THETA) 22 (PHI)	10 (PSI)	--

RIGHT LEG SYSTEM

JOINT NO./ LINK NO.	JOINT NAME/ LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
28	PELVIC LATERAL	--	--	34 (THETA) 35 (PHI) 36 (PSI)
30	FEMORAL	28 (THETA) 29 (PHI) 30 (PSI)	--	--
32	TIBIAL	31 (THETA) 32 (PSI)	12 (PHI)	--
34	FOOT	33 (THETA) 34 (PHI)	13 (PSI)	--
36	HEEL-TOE	--	--	37 (THETA) 38 (PHI) 39 (PSI)

LEFT LEG SYSTEM

JOINT NO./ LINK NO.	JOINT NAME/ LINK NAME	VARIABLE ANGLE NO.	CONSTANT ANGLES	FIXED ANGLES
27	PELVIC LATERAL	--	--	40 (THETA) 41 (PHI) 42 (PSI)
29	FEMORAL	35 (THETA) 36 (PHI) 37 (PSI)	--	--
31	TIBIAL	38 (THETA) 39 (PSI)	14 (PHI)	--
33	FOOT	40 (THETA) 41 (PHI)	15 (PSI)	--
35	HEEL-TOE	--	--	43 (THETA) 44 (PHI) 45 (PSI)

In addition, these bounds are stored more compactly in bound arrays (upper and lower) and the angle numbers and joint numbers for variable angles are initialized in separate arrays.

The calling sequence for SETUP is

(J, IND, TEMP, ANG, SPOS, W, IQ, IPAR, K1, K2, K3, C, FL, FLR, FLR1, F, DR, II) where

J = joint number in a link system (input)

IND(I) = a control array used to differentiate between fixed angles in variable joints,; I = 1, 2, 3 (output)

TEMP(I) = temporary storage array for two joint angular values (output)

ANG(I,J) = lower and upper bounds of all joint angles (input)

SPOS(I,J) = standard angular values for all joints (input)

W(I) = variable angle values used in MAN1 calculations I = 1, K1 (output)

IQ(I) = array preserving the place in a joint number sequence to which variable angle I belongs I = 1, K1 (output)

IPAR(I) = array preserving the kind of angle (θ, φ, or ψ) to which variable angle I belongs (I = 1, K1) (output)

K1 = number of variable angles (output)

K2 = number of constant angles in variable joints (output)

K3 = number of constant angles in fixed joints (output)

C(I) = constant angle value array (I = 1, K2) (output)

FLR(I) = FL(I) = constant angle value array (I = 1, K3)
(output)

FLR1(I) = difference of two constant angles in a joint
I = 1, K3 (output)

F(I,J) = matrix of constant trigonometric functions of
angles used for calculation in TRANSF I = 1, 2
J = 1, 3, (output)

DR = 1.0 constant (input)

II = position number in a link system (input)

SETUP calls ROT3 to calculate the value of the rotation
matrix F.

SUBROUTINE ROT3

This subroutine initializes a rotation matrix T (see Section 2.4 of Math Model Document) used later in MAN1 overlay. For general use of this subroutine, see page in the MAN1 subroutine section.

The calling sequence for ROT3 is CALL ROT3(J) where J = joint number in a link system (input); in addition the variables JDER and F, transmitted through COMMON/ ROTATE/, must be preset. F(I,J) is the matrix of trigonometric functions of the constant anglesgiven above, and JDER = 4 allows for the calculation of rotation matrix T.

Output from this routine is the rotation matrix T(I,I1,I2) of angles in a joint (I = 1, 3; I1 = 1, 3; I2 = joint number, K = 1, NL).

SUBROUTINE TRANSF

This subroutine is used to calculate a sequence of joint locations for a link system, given the link lengths, corresponding rotation matrices, and an initial joint location (either the lumbar joint or top of spine point).

Subroutine TRANSF is used predominantly in the MAN1 overlay for joint position calculation and evaluation of joint derivatives with respect to the Euler angles. A description for derivative calculation is given in the MAN1 subroutine section.

The calling sequence for TRANSF is

CALL TRANSF (V, IT, LB, LUB, K, L, MNA, MNP, LJOIN, JABOS, IDER) where

V(I) = variable joint angle array = WR(I), (input)
I = 1, K1 (number of variable angles)

IT(I) = array of joint numbers for a specified link system
(i.e., ISPRA, ILA, IH, ILL, IRL) (input) I = 1, 10 maximum

LB = lower bound on the subscript I of IT(I) (input)

LUB = upper bound on the subscript I of IT(I) (input)

K = integer denoting the first constant angle of a variable joint (C, SCON, CCON) that the subroutine encounters in a link system.

L = integer denoting the first variable angle (of IQ array) that the subroutine encounters in a link system (input)

MNA = maximum number of angles BOEMAN-I (input)

MNP = maximum number of points (joints) of BOEMAN-I (input)

LJOIN = number of Euler angles in the spine that are variable in V(I) (input)

JABOS = denotes the joint succeeding the initial reference joint number (top or bottom of spine) upon which link system calculatinns are based (input)

IDER = control variable determining whether or not joint derivatives are to be calculated

$$\text{IDER} = \begin{cases} 0 & \text{no derivatives} \\ 1 & \text{calculate derivatives} \end{cases} \qquad \text{(input)}$$

Additional input required by this routine, transmitted via block common includes:

IQ(I), IPAR(I) arrays referencing joint and angle number subscripts, T(I, I1, I2), the joint rotation matrix (I2 = 1, NL; I = 1, 3, I1 = 1, 3) F(I,J), (I = 1, 2; J = 1, 3), the array of trigonometric functions of the Euler angles defining T, TIP (I,J) (I = 1, 3; J = 1, 3) references the transformation matrix at the initial joint of the sequence (bottom or top of the spine), TRNSLT(I), (I = 1, NL) the lengths of the 36 links, CCON (I), SCON(I), the sines and cosines of the constant angles in rotations T having at least one variable Euler angle V(J).

JDER, the control variable for subroutine ROT3, TP(I, J) (I = 1, 3; J = 1, 3), the current transformation matrix at a joint, and P(I, J) (I = 1, 3; J = 1, NL), the joint location array in (x, y, z) coordinates are direct output.

TP(I,J) stores the current value of the product of rotation matrices T when tracing a sequential link system such as ISPRA.

SUBROUTINE MAB

This subroutine performs the matrix multiplication C = AB where A is L x M, B is M x N.

It has two entry points MATB and MABT where one calculates $C = A^T B$ and $C = AB^T$ respectively.

The calling sequence for MAB is

CALL MAB (A, B, C, L, M, N, NRA, NRB, NRC)

A = matrix to be premultiplied, (L x M), (input)

B = matrix to be post multiplied, (M x N), (Input)

C = resultant matrix, (L x N), (output)

L = number of rows of A, Input)

M = number of columns of A and rows of B, (input)

N = number of columns of B, (input)

NRA = number of rows of A, (input)

NRB = number of rows of B, (input)

NRC = number of rows of C, (input)

SUBROUTINE AFF

This subroutine finds the first derivative of the position vector P(J, IT(I)), with respect to the LLth variable angle used in transforming from system IT(M) to IT(M+1), where M $\angle$ I. (See Section 2.4 of Math Model Document).

The calling sequence is

CALL AFF (NCALL, IT, I, LL, DP, NC) where

NCALL = control variable

$$= \begin{cases} 1 & \text{calculate derivative of initial position vector} \\ 2 & \text{calculate derivative of any other position vector} \\ 3 & \text{calculate position vector only} \end{cases}$$

IT(I) = array of joint numbers for a specified link system (input)

I = integer designating the Ith place in the joint number sequence (input)

LL = the derivative number to be calcuäated (input)

DP = the angle derivative of the joint position vector (used in this case as P(J, IT(I)) itself), (output)

NC = number of columnsof derivative array DP (maximum number of angles)

The routine utilizes the following additional input from

Block Common

TP (I1, I2) - transformation matrix at a joint (I1.= 1, 3; I2 = 1, 3).

DTP(I1, I2, I3) - Joint derivative array of the transformation matrix with respect to each joint angle (I1 = 1, 3, I2 = 1, 3, I3 = 1, maximum number of angles).

TRNSLT(I1) = link lengths (I1 = 1, number of links)

SUBROUTINE DTPF

This subroutine calculates the first derivative of the product array TP of rotation matrices T(I, J, IT(M)) with respect to the LLth variable angle , where M is the MAN1 overlay but must be included whenever TRANSF is called (since INTRAN does not require derivative calculations).

The calling sequence is

CALL DTPF (NCALL, JT, LL) where

$$\text{NCALL} = \begin{cases} 1 & \text{calculate product array TP} \\ 2 & \text{calculate angle derivative of product array TP, (input)} \end{cases}$$

JT = joint number (set from IT(I)), (input)

LL = derivative number of product array TP (input)

Input variables transmitted from block common include

IPAR(I1) = array of joint angle specifiers (I1 = 1, number of variable angles)

TP (I1, I2) = transformation matrix at a joint (I1 = 1, 3; I2 = 1, 3)

DTP(I1, I2, I3) = angle derivatives of array TP (I1 = 1, 3; I2 = 1, 3; I3 = 1, Maximum number of angles)

DT(I1, I2, I3) = angle derivative matrix of rotation matrix T (I1 = 1, 3; I2 = 1,9; I3 = 1, number of joints)

T(I1, I2, I3) = rotation matrix at joint I3 (I1, I2 = 1, 3; I3= 1, number of joints)

SUBROUTINE KOMPAR

Subroutine KOMPAR is a system routine which tests whether two variables store identical values. Its calling sequence is

CALL KOMPAR (A, B, C) where

A = first variable to be compared, bit by bit (input)

B = second variable to be compared, bit by bit (input)

$$C = \begin{cases} 0 & \text{A and B are identical} \\ \neq 0 & \text{A and B differ} \end{cases}$$

A more detailed discussion of KOMPAR may be found in Reference 3.

PROGRAM REACHA

This program initializes all data needed for Subroutine PREANL, which determines the gross feasibility of the task that BOEMAN-I is currently undertaking. It also presents array PTF, used in the MAN1 overlay to the terminal eye and hand joint locations, and final hand orientations of the task. When the preanalysis has been completed, the task number and feasible top of spine position are optionally written on the intermediate output tape. If the task is deemed infeasible, the final palm positions are redefined and their distances from the original task-defined positions are calculated and all pertinent information is written on the intermediate output tape. This program calls Subroutine PREANL which in turn calls the remainder of the subroutines of this overlay.

SUBROUTINE PREANL

This subroutine calculates a feasible top of spine position given the palm positions of the hands (task defined) and the location of the lumbar joint according to an optimization procedure described in the Math Model Document (Section 2.3). The optimization routine utilized is called MINUM.

The calling sequence for PREANL is given by

CALL PREANL (AA, BB, ALPHA, BETA, XO, YO, ZO, X1, Y1, Z1, RHØ1, RHØ2, X2, Y2, Z2, SIGMA1, SIGMA2, X3, Y3, Z3, IREDEF, X11, Y11, Z11, X22, Y22, Z22, L1, L2, L3, L4, L5) where

AA = Lumbar link length (= LINKS(1)), (input)

BB = thoracic link length (= LINKS(3)), (input)

ALPHA = angle φ limit on lumbar joint (=ANGLIM(2,1)), (input)

BETA = angle φ limit on thoracic joint (=ANGLIM(2,3)), (input)

$$\left.\begin{array}{l}\text{XO = x coordinate}\\ \text{YO = y coordinate}\\ \text{ZO = z coordinate}\end{array}\right\}\ \begin{array}{l}\text{of initial top of the spine position}\\ \text{(= P(I, 3), I = 1, 3), (input)}\end{array}$$

$$\left.\begin{array}{l}\text{X1 = x coordinate}\\ \text{Y1 = y coordinate}\\ \text{Z1 = z coordinate}\end{array}\right\}\ \begin{array}{l}\text{of right hand control point}\\ \text{(= RHTPT(I,JTASK), I= 1, 3), (input)}\end{array}$$

RHØ1 = radius from right hand control point to top of spine with arm in contracted attitude, (input)

RHØ2 = radius from right hand control point to top of spine with arm in extended attitude (straight arm)

X2 = x coordinate
Y2 = y coordinate
Z2 = z coordinate
} of left hand control point (= LHTPT(I,JTASK), I = 1, 3), (input)

SIGMA1 = radius from left hand control to top of spine, arm in contracted attitude (input)

SIGMA2 = radius from left hand control to top of spine arm in extended attitude, (input)

X3 = x coordinate
Y3 = y coordinate
Z3 = z coordinate
} of feasible top of spine position (input)

IREDEF = { 1 Task is feasible
2 Task controls have been redefined (output)

X11 = x coordinate
Y11 = y coordinate
Z11 = z coordinate
} of redefined right palm position (output)

X22 = x coordinate
Y22 = y coordinate
Z22 = z coordinate
} of redefined left palm position (output)

L1 = one-half of the interclavicular link length (= LINKS(12)), (input)

L2 = clavicular link length (= LINKS(14)), (input)

L3 = humeral link length (= LINKS(18)), (input)

L4 = radial link length (= LINKS(20)), (input)

L5 = wrist to palm link length (= LINKS(24) or LINKS(26)), (input)

This subroutine also initializes variables used in Subroutine MINUM, which it calls repeatedly with each of the FUNCTIONS FUN1, FUN2, FUN3, FUN4, FUN5, FUN6, and FUN7 and Subroutine REDEF.

SUBROUTINE MINUM

This subroutine calculates the minimum value of a function of N parameters whose values range from 0 to 1, using techniques of random direction gradient direction, average direction and jump steps in a user-prescribed mixture.

The calling sequence for this routine is

CALL MINUM (N, PARM, A, FUN, IU, IX, ISTP, IPRINT, JR, JG, JA, JJ, AA, BB, ALPHA, BETA, XO, YO, ZO, QQ, Y1, Z1, RHØ1, RHØ2, X2, Y2, Z2, SIGMA1, SIGMA2, R, RR, DELTA) where

N = number of parameters = 3, (coordinates of top of spine location), (input)

PARM(I) = array of given starting values for parameters (mapped to [0, 1] coordinate system) and final values for parameters (input/output)

A(I,J) = working storage array dimensioned at least 7 x N, (input)

FUN = name of function to be minimized (i.e., FUNi, i = 1, 7) (input)

IU = start multiplier for random number generator subroutine RAND (IU must be odd; IU = 3746531 currently), (input)

IX = fixed multiplier for RAND (currently IX = 16777213), (input)

ISTP = total number of steps to be tried (currently ISTP = 1000), (input)

IPRINT = $\begin{cases} -1 & \text{suppress printing} \\ +i & \text{print out at every } i^{th} \text{ step} \end{cases}$ (input)

JR = unnormalized frequency of use of random step
(currently JR = 1), (input)

JG = unnormalized frequency of use of gradient step
(currently JG = 20), (input)

JA = unnormalized frequency of use of average step
(currently JA = 1), (input)

JJ = unnormalized frequency of use of jump step
(currently JJ = 1), (input)

AA = lumbar link length, (input)

BB = thoracic link length, (input)

ALPHA = angle φ limit on lumbar joint, (input)

BETA = angle φ limit on thoracic joint, (input)

$\left.\begin{array}{l} X0 \\ Y0 \\ Z0 \end{array}\right\}$ = coordinates of initial top of spine position, (input)

$\left.\begin{array}{l} QQ \\ Y1 \\ Z1 \end{array}\right\}$ = coordinates of right hand control point, (input)

$\left.\begin{array}{l} RH\emptyset 1 \\ RH\emptyset 2 \end{array}\right\}$ = Radii from right hand control point to top of spine, in contracted and extended arm attitudes respectively, (input)

$\left.\begin{array}{l} X2 \\ Y2 \\ Z2 \end{array}\right\}$ = coordinates of left hand control point, (input)

SIGMA1 radii from left hand control point to top of spine in contracted and extended arm attitudes,
SIGMA2 respectively, (input)

R = minimum distance between top and bottom of spine, (input)

RR = maximum distance between top and bottom of spine, (input)

DELTA = angle between X-Y plane (horizontal) **and line from** bottom of spine to top of spine with links at maximum angular deviation (input)

FUNCTIONS FUNi (i = 1, ---, 7)

Functions FUN1, ---, FUN7 are used by MINUM and PREANL to evaluate objective functions with a penalty function representing constraints. Each is of the form

FUNi = OBJ + (PENALTY) where

$$\text{OBJ} = \begin{cases} (X-X0)^2 + (Y-Y0)^2 + (Z-Z0)^2 & i = 1, 2, 3 \\ (X5-X)^2 + (Y5-Y)^2 + (Z5-Z)^2 & i = 4 \\ (X-XM)^2 + (Y-YM)^2 + (Z-ZM)^2 & i = 5, 6, 7 \end{cases}$$

$$\text{PENALTY} = \sum_{j=1}^{6} C_j \quad \text{for all } i = 1, 7$$

For each i, however, the content of the constraint set differs. The C_j (j = 1, --, 6) are the problem constraints, as specified in Section 3.2 of the Math Model Document.

The calling sequence is

V = FUNi (PARAM, AA, BB, ALPHA, BETA, X0, Y0, Z0, XI, YI, ZI, RHØ1, RHØ2, X2, Y2, Z2, SIGMA1, SIGMA2, R, RR, DELTA, C1, C2, C3, C4, C5, C6, OBJ, X, Y, Z) where

PARAM = normalized coordinates of a feasible top-of-spine position, (input)

and variables AA through DELTA are as described in the sequences of PREANL and MINUM, and

C_j, j = 1, ---, 6) are constraint equations evaluated at coordinates (X, Y, Z), (functions of PARAM), (output)

OBJ = value of objective function at (X, Y, Z), (output)

$\left.\begin{matrix}X\\Y\\Z\end{matrix}\right\}$ = coordinates (unnormalized) of top-of-spine (evaluation point), (output)

V = value of FUNi evaluated at PARAM(J), J = 1, 3

SUBROUTINE REDEF

This subroutine redefines the task specified control points for each hand for an initially infeasible task.

The calling sequence is

CALL REDEF (X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X11, Y11, Z11, X22, Y22, Z22, L1, L2, L3, L4, L5).

These variables are defined in PREANL and all but X11 through Z22 are input variables.

MINUM invokes the use of a system subroutine, called **RAND which** generates random numbers for use in the calculation of steps and search directions in the optimization technique.

The calling sequence is

CALL RAND (IU, IX, K, N, U) where

IU = variable start multiplier, an odd-number:

$2^{24} \angle$ IU $\angle 2^{25}$, (input/output)

IX = fixed start multiplier, $2^{23} \angle$ IX $\angle 2^{25}$, IX = $8n \pm 3$

where $1048537 \angle n \angle 4194307$, (input)

K = an indicator specifying normal or uniform distribution

(K = 1, K = 0 respectively) (K = 0 currently), (input)

N = number of random numbers desired (N = 1 currently), (input)

U = an array of N uniformly or normally distributed

variables. If uniform, then $0 \angle U(J) \angle 1$,

J = 1, ---, N.

Program MAN1

MAN1 is the main program for the motion-model overlay which generates step-by-step task motion for a seated human pilot. It requires that the initial position of BOEMAN-I (with Euler angles) be completely specified, and the control points to be reached and viewed, along with final hand orientations, also be given. It calls the subroutines RYTE, TASK, POSE and LYNX. RYTE through POSE represent utility routines for writing, position calculation and final step constraints for the hands and eyes respectively. LYNX is the main routine enbodying the optimization procedure. If at any time during the task an infeasibility condition occurs, checks for violation of the task defining constraints and body-restriction constraints are made and violations are written on the intermediate output file. An infeasibility condition occurs if

(1) The completed number of minimizations to generate a BOEMAN-I position for a step exceeds 5

(2) The value of the penalty function exceeds the maximum allowable constraint error value EP2=1 inch

(3) The distances between the final hand positions and the hand control points exceed EP3=1 inch

If the task is feasible, position locations (R) and orientation angles (ANGLE1) for each step are written on the intermediate output file. Furthermore, these position locations (RG) are preserved on a binary file for the interference overlay as it tests for physical interference.

Subroutine RYTE

RYTE lists the input to MAN1 and writes out BOEMAN-I joint locations for each step, control points and constraint violations, preferred angles, objective function weights and angular bounds.

The calling sequence is

CALL RYTE (NCALL)

where NCALL = an integer specifying the kind of printout desired by the calling routines. (input)

i.e.,

NCALL =
1 write out input data to MAN1
2 write out reinitializing man message
3 write out go onto next task message
4 write out position vectors and rotation matrices for steps between 2nd and next to last step
5 write out position vectors and rotation matrices for final step

Other input from block common includes

MAN
≤ 0 suppress all printout from this routine and return
> 0 continue as specified by NCALL

MAN is a fixed control parameter, specified by the user at the beginning of a run.

Subroutine TASK

TASK specifies "control points" along the palm joint straight line paths corresponding to a given step during a task. It also determines the number of steps comprising a task. In the final position (step), hand orientation and directional (line of sight) constraints are also set up. This routine calls: Subroutine LINE and RØ3.

The calling sequence is:

CALL TASK (NCALL)

where

NCALL = as input, a positive integer specifying the entry for TASK; as output, it specifies whether or not optimization is to be called.

Other input from block common includes:

DR = 1.

ISKIP = 1 if optimization is not to be called for the first position calculation of a task
≠ 1 any other integer otherwise

KPOS = the number of the current position in a task

N = the number of parameters (variable Euler angles) in the stick-man for a task.

NSTEPS = as input, the maximum distance to be moved by either hand from one position to the next, in integral inches if a positive integer; if negative, its absolute value is the reciprocal of the above quantity.

PTI(I)(I=1,12) = the vector of equality constraints at the beginning of a task.

PTF(I)(I=1,15) = the same vector for the end of a task; elements 13, 14, and 15 are the coordinates of the eye control point

STEPS = the number of positions for the current task

Output variables from block common include

M = the number of equality contraints for a call to optimization routine LYNX

NSTEPS = the number of steps in which the next task is to be executed.

PT(I)(I=1,15) = the array in which the equality constraints for a call to LYNX are stored.

Subroutine RØ3

RØ3 calculates the three-space rotation matrix given Euler angles THETA, PHI, PSI. There is an entry point denoted RØ3F if the sine and cosine functions of the Euler angles are specified.

The calling sequences are

```
CALL RØ3(THETA,PHI,PSI,RØT)
```

where THETA, PHI, PSI are Euler angles (input) and RØT (output) is a 3-space rotation matrix calculated from these angles.

```
CALL RØ3F (THETA,PHI,BSI,ROT)
```

where

$$\left.\begin{array}{l}\text{THETA}\\ \text{PHI}\\ \text{PSI}\end{array}\right\}\qquad \text{Dummy variables}$$

$$\text{ROT(I,J)}=\begin{bmatrix}\text{sin (THETA)} & \text{sin (PHI)} & \text{sin(PHI-PSI)}\\ \text{cos (THETA)} & \text{cos (PHI)} & \text{cos (PHI-PSI)}\\ 0 & 0 & 0\end{bmatrix}\qquad \text{(input/output)}$$

as input and is a 3 space rotation matrix calculated from these angle functions.

Subroutine LINE

LINE performs linear interpolation for a line, given its end points as vectors in Euclidean three space.

The calling sequence is

```
      CALL LINE (P1,P2,P,T,I,N)
```

where P1 and P2 are points in N-space (input) and P (output) is a point on the line through P1 and P2, to be found using the information supplied by I and the scalar T (input).

If I = 0, T is used to scale the difference of P2 and P1 and thus determine P on the straight line joining them.

If I = 1,2,3, then a point P on the straight line joining P,P2 is found, having T as its I^{th} coordinate.

Subroutine PØSE

PØSE calculates the position vectors for all of the joints of BOEMAN-I given the Euler angles for each joint. It utilizes subroutine TRANSF for these calculations. This routine is similar in intent to subroutine ANGLET of the INTRAN overlay which calculates the standard starting position.

The calling sequence is

```
     CALL PØSE
```

Input is transmitted entirely through block common and includes

DR = previously defined

IC = the label of eye midpoint of the stickman

IH(I)(I=1,8) = the same for the spine - head system (see ISPRA)

IJOIN = the label of the top of the spine

ILA(I)(I=1,10) = the same for the spine - left arm system (see ISPRA)

ISPRA(I)(I=1,10) = the link-connecting point (joint) labels in the spine and right arm, starting with the top of the lumbar link and ending with the tip of the right hand

IUB = the number of link - connecting points (or joints) in the spine and eigher arm of the stickman

LJØIN = the number of variable Euler angles in the spine link - system

N = number of variable Euler angles

NUB = the number of link - connecting point (joints) in the spine and head system, including eye midpoint and an extra point one inch beyond the eye midpoint

TRNSLT(I)(I=1,36) = the link lengths for the stickman, indexed by the labels of corresponding link - connecting points, such as the positive integer elements of ISPRA.

X(I)(I=1,N) = the vector of variable Euler angles (parameter vector for optimization) that define a position of the stickman

Output from block common includes

ALEPH(I)(I=1,3) = a unit vector based at the eye midpoint of the stick-man, showing the direction in which the stick-man is actually looking

BETH(I)(I=1,3) = a unit vector giving the line-of-sight direction from eye midpoint to the eye control point in the cockpit

BETHN = the distance from the eye midpoint to the eye control point

BETHNS = the square of BETHN

P(I,J)(I=1,3;J=1,36) = the coordinates of all 36 link - connecting points and terminal points (e.g., finger-tips, eye midpoint) on the stickman

PF(I)(I=4,5,6,10,11,12) two 3-dimensional unit vectors representing right hand and left hand orientation, respectively

TIP(I,J)(I=1,3;J=1,3)= the product of the 3-space rotation matrices T(I,J,K) where I,J, and K vary from 1 to 3, K increasing from the left in the product

TP(I,J)(I=1,3;J=1,3) = the product of rotation matrices T(I,J,K) starting with the bottom of spine joint and proceeding (from left to right) as K varies over the indices of a sequential system on the stickman. TIP(I,J) is a special case, the sequential system being the spine link-connector whose labels (indices) are 1,2, and 3.

SUBROUTINE SPRING

SPRING computes the value of the objective function to be minimized. Currently the sum of squares of the differences between the orientation angles and the preferred angle values with weight coefficients comprise the objective function, i.e.,

$$FX = \sum_{i=1}^{N} G(I) * A(I)$$

where $G(I) = C\O NST(I) * A(I)$

$A(I) = (X(I) - C\O NST(I+N))$

The calling sequence is:

CALL SPRING(X,FX)

where X(I) (I=1,N) = the current value of the parameter vector (input)

FX = the objective function value (output)

Input variables from block common are:

CONST(I) (I=1,2*N) = the constants needed for the objective function

IPAR(I) (I=1,N) = previously defined (see TRANSF)

M = see TASK

N = see PØSE

Output variables from block common:

A(I) (I=1,N) = differences between the variable angles and its preferred values stored to avoid repetition for the gradient calculation performed in SPRINX

SUBROUTINE SPRING- Continued

G(I) (I=1,N) = weighted differences between the variable angles and its preferred values

SUBROUTINE SPRINX

SPRINX calculates the Gradient of the objective function (generated by Subroutine SPRING) with respect to each variable Euler angle. i.e.,

```
     GX(I) = 2 * G(I)
```

The calling sequence is

```
     CALL SPRINX(X,GX)
```

where X(I) (I=1,N) is as defined for SPRING (input)

GX(I) (I=1,N) = the gradient value of the objective function at X (output)

Input from block common includes

A(I) (I=1,N)	see SPRING
G(I) (I=1,N)	see SPRING
IPAR(I) (I=1,N)	see TRANSF
N	see PØSE

There is no output through block common.

SUBROUTINE PØC

PØC calculates the equality constraints (link constraints) given a BOEMAN-I position at each step and the hand orientations to be assumed at the final step. The line of sight constraint for the eye is also calculated for the final step. To accomplish these items, PØC calls subroutine TRANSF, obtaining position vectors and PT derivatives of position vectors with respect to the variable angles.

The calling sequence is

```
    CALL PØC(X,PF)
```

where X(I) (I=1,N) is as defined in SPRING (input)

PF(I) (I=1,M) = the value of the constraint vector at X (output)

Input from block common includes

DR	=	1
IA	=	the label of the right arm terminal point
IB	=	the same for the left arm
IC		see PØSE
IH(I) (I=1,8)		see PØSE
IJØIN		see PØSE
IJP1	=	IJØIN+1
ILA		see PØSE
ISPRA		see PØSE
IUB		see PØSE
KCALL	=	information from RAKE, which handles all function calls to LYNX, telling PØC whether or not to call for derivatives for the gradient calculation in PØCX.

SUBROUTINE PØC - Continued

LA	= the number of variable Euler angles in the spine right arm (ISPRA) system
LAL	= LA + 1, the index of the first angle in the left arm system (ILA(I), I=4,10)
LB	= LA + (number of angles in the left arm system)
LJØIN	see PØSE
M	see TASK
N	see PØSE
NUB	see PØSE
PT(I) (I=1,15)	see TASK
TRNSLT(I) (I=1,36)	see TRANSF

Output from block common includes

ALEPH(I) (I=1,3)	see PØSE
BETH(I) (I=1,3)	see PØSE
BETHN	see PØSE
BETHNS	see PØSE
DLEFT(I,J) (I=1,3; J=1, LB-LA)	= the DP array for the left arm
DRIGHT(I,J) (I=1,3; J=1, LA)	= the DP array for the right arm
DP(I,J,K)	see TRANSF
DTIP(I,J,K) (I=1,3; J=1,3; K=1, LJØIN)	see TRANSF
DTP(I,J,K) (I=1,3; J=1,3; K=1,42)	see TRANSF
P(I,J) (I=1,3; J=1,36)	see PØSE
TIP(I,J) (I=1,3; J=1,3)	see PØSE
TP(I,J) (I=2,3; J=1,3)	see PØSE

SUBROUTINE PØCX

PØCX calculates the gradient matrix (PX) of the constraint vector (PF), using the first derivatives (DP) of the position vector (P) obtained by subroutine PØC. This routine calls no other subroutines.

The calling sequence is

```
     CALL PØCX (X,PX)
```

where X(I) (I=1,N) is as defined in SPRING (input)

PX(I,J) (I=1,N; J=1,M) = the current value of the Jacobian matrix of the vector function PF at X (output)

Input from block common includes

ALEPH(I) (I=1,3)	see PØSE
BETH(I) (I=1,3)	see PØSE
BETHN	see PØSE
BETHNS	see PØSE
DLEFT(I,J) (I=1,3; J = 1, LB-LA)	see PØC
DRIGHT(I,J) (I=1,3; J=1,LA)	see PØC
DP(I,J,K) (I=1,3; J=1,42; K=1,36)	see TRANSF
IA	see PØC
IB	see PØC
IC	see PØSE
LA	see PØC
LAL	see PØC
LB	see PØC
LBL	see PØC
LJØIN	see PØSE

SUBROUTINE PØCX - Continued

M	see TASK
N	see PØSE

There is no output through block common.

SUBROUTINE TRANSF

TRANSF calculates joint locations and/or their first derivatives with respect to the variable Euler angles. They are generated for a sequential array of points connected by links. The Euler angles, together with arrays defining the structure of the link system are input. TRANSF calls subroutines AFF, DTPF and RØT3 for its calculation.

This routine is also present in the INTRAN overlay, where calculation of joint locations is described without derivative calculations. (IDER = 0)

To calculate joint locations and their first derivatives requires that the variable IDER be set to 1.

The calling sequence is

```
     CALL TRANSF(V,IT,LB,LUB,K,L,MNA,MNP,LJØIN,JABØS,IDER)
```

where V(I) (I=1,N) = the variable Euler angles, from the bottom-of-spine joint to terminal joint, for the spine-right arm system (ISPRA), plus the angles for the other sequential systems, each set of angles beginning with the top of spine and proceeding to the terminal joint for that system. At present, the systems appear in the order ISPRA, ILA, IH (input)

IT(I) (I=LB,LUB) = one of ISPRA, ILA, or IH, giving the indices K for the link-connectors P(I,K) and rotation matrices T(I,J,K) of a sequential system

SUBROUTINE TRANSF - Continued

on the stickman. LB defines the location in the IT (e.g., ILA) array at which the system for this call to TRANSF joins on to the body (e.g., where the left arm joins the top of the spine), and LUB defines the end of the system (e.g., tip of left hand)

LB defined above (input)

LUB defined above (input)

K = the current value of the index of the arrays SCØN and CCØN (see below) (input/output)

L = the current value of the index of V (input/output)

MNA = dimensioning information for calls to utility routines used by TRANSF. e.g., DTP should be dimensioned DTP (3,3,MNA). (input)

MNP = the same information for the dimension P(3,MNP) (input)

LJØIN = the number of variable angles V(I) at which the system IT joins other systems, counting from the origin of all systems on the stickman (e.g., see definition in PØSE writeup) (input)

JABØS = the index (label) of the link-connector P(I,JABØS) (I=1,3) in the IT system that joins to the bottom of the spine; in systems ISPRA,ILA, and IH, JABØS = 1. (input)

SUBROUTINE TRANSF - Continued

IDER = 1 if derivatives with respect to Euler angles of the points P(I,K) in the IT system are desired; IDER = 0 if only the coordinates of the points themselves are wanted. (input)

Input from block common includes

CCØN(I) = the cosines of the constant Euler angles in variable transformations T(I,J,...), corresponding to movable link-connectors (joints). I ranges from the input value of K to the output value during a call to TRANSF.

DTIP(I,J,K) = the derivatives with respect to the variable Euler angles V(K) of the array TIP(I,J), defined in the PØSE writeup

IQ(I) = the value of the index of the array IT , which gives the index of the transformation T(J,K,IT) for which V(I) is a variable Euler angle

IPAR(I) = = 1 if V(I) is the Euler angle θ

= 2 if V(I) is the Euler angle φ

= 3 if V(I) is the Euler angle ψ

in transformation T(J,K,IT(IQ(I)))

SCØN(I) = the sines corresponding to the cosines in CCØN(I)

TIP(I,J) = defined in PØSE writeup

TRNSLT(I) = the link lengths of the links in the stickman

Output from block common includes

DP(I,J,K) (I=1,3; J=1,42; K=1,36)

= the derivatives with respect to variable Euler angles V(J) of link-connecting points P(I,K)

DT(I,J,K) (I=1,3; J=1,9; K=1,36)

= the derivatives with respect to the variable Euler angles in transformation T(I,J,K) (where J=1,3) of T(I,J,K)

DTP(I,J,K) (I=1,3; J=1,3; K=1,42)

= the derivatives with respect to Euler angles V(K) of TP(I,J), which is defined in the PØSE writeup

F(I,J) (I=1,2; J=1,3)

= the sines and cosines of all Euler angles for a transformation T or its derivative DT ; F is used to transfer these functions to RØT3 , which calculates T and/or DT

JDER = the variable specifying whether T or one of the three derivatives DT is to be calculated in RØT3 . If JDER = 4, T is calculated. JDER = 1,2,3 means calculate the derivative of T with respect to Θ, φ, or ψ.

T(I,J,K) (I=1,3; J=1,3; K=1,36)

= the 3X3 rotation matrix for the rotation needed to transform for the local coordinate system aligned with link K-1 to that aligned with link K.

SUBROUTINE TRANSF - Contimued

P(I,J) (I=1,3; J=1,36)

= the coordinates of the link-connectors J , some of which are movable (i.e., are joints), all expressed in the cockpit reference system based at the bottom of the stickman spine.

TP(I,J) (I=1,3; J=1,3)

= defined in PØSE writeup

SUBROUTINE AFF

AFF generates a rotation and translation of a point (position vector) in three-space and calculates the first derivatives of the point with respect to the variable Euler angles.

AFF appears and is described in the INTRAN overlay.

SUBROUTINE DTPF

DTPF computes the first derivative with respect to Euler angles of a product of rotation matrices based on the Euler angles. It calls Subroutine MAB to generate the necessary products.

DTPF appears and is described in the INTRAN overlay.

SUBROUTINE RØT3

RØT3 calculates the 3-space rotation matrices and their first derivatives with respect to their corresponding Euler angles.

RØT3 appears and is described in the INTRAN overlay.

SUBROUTINE LYNX

LYNX embodies optimization procedure and minimizes a non-linear objective function of N variablessubject to non-linear equality constraints. It uses the Davidon variable metric method (where H is the variable metric matrix). This method initially established a search direction along the line of steepest descent and a relative minimum is bracketed in an interval (X(I),X(I)+ETA*S(I)). If the objective function value is still decreasing on the interval, then the interval is too small and a larger interval is chosen. Once a good interval is established, the location of the minimum is estimated on that interval using cubic interpolation. If this is not sufficient to locate the minimum, an estimate is made using the golden section technique. Once a relative minimum is established, the H matrix is modified and the next search direction is specified on the basis of H and the procedure is repeated. The procedure stops when the absolute distance from the minimum does not exceed ERR.

At this point, a new objective function based on an increased penalty function term embodying the constraints is set up and the optimization procedure is tried again. When the components of the constraint vector do not exceed the constraint error ERC, the algorithm is completed and variable orientation angles for a single step have been generated. This subroutine calls subroutines CTERP, FTERP, RAKE, PENLTY, REPLCE, HBAD, MAB, and TRAC.

The calling sequence is

```
     CALL LYNX(FUN,DER,PENF,PENFX)
```

where FUN = the formal name of the objective function to be minimized (input)

DER = the gradient of FUN with respect to the optimization parameters (input)

PENF = the vector function that calculates the vector of equality constraints (input)

PENFX = the gradient of PENF (input)

These parameters must be declared with an EXTERNAL statement in any routine which calls LYNX.

Input from block common includes

IP = the output option for the amount of information to be printed out by the output routine TRAC

ERC = the allowed error in satisfying each equality constraint for a call to LYNX

ERR = the allowed error in approaching the constrained minimum of the objective function during a Davidon minimization

LM = the upper bound on the number of Davidon minimizations during a call to LYNX. If the optimization procedure has not converged by the time the number of minimizations (KKØUNT) reaches LM, LYNX is forced to return with the current approximation to the solution.

M = defined in Subroutine TASK

N = defined in Subroutine PØSE

SUBROUTINE LYNX - Continued

SCALE = the number by which the penalty coefficient PK is to be multiplied between Davidon minimizations.

X(I) (I=1,N) = defined in the PØSE writeup; as output, X is the solution vector of variable Euler angles for a stickman position

Output from block common includes

FX = the objective function value at the time LYNX returns to the calling program

GX(I) (I=1,N) = the gradient at return

KKØUNT = the number of Davidon minimizations completed during optimization

KØUNT = the number of iterations performed during the final Davidon minimization in the optimization procedure

PF(I) (I=1,M) = the final value of the constraint vector, with M equality constraints

PK = the penalty function coefficient; PK is multiplied by SCALE every minimization

PXN = the final value of the penalty function, including the factor PK .

SUBROUTINE CTERP

CTERP performs the one-dimensional minimization of a function of many variables using the method of cubic interpolation to estimate the location of a relative minimum on an interval. CTERP calls subroutine RAKE to check the objective function value at the estimated location.

The calling sequence is

```
     CALL CTERP(FUN,DER,PENF,PENFX)
```

where FUN, DER PENF, and PENFX are externals which have been previously defined.

Input from block common includes

ETA = the estimated scale factor for the search vector S ; i.e., the search interval for a Davidon iteration lies between the starting point X and the point V = X + ETA * S

FX = defined previously

FY = the value of the objective function at V = X + ETA * S

GSX = the one-dimensional derivative of the objective function in the direction of search, evaluated at X . GSX = -(GX-TRANSPOSE) * H * GX , where H = Davidon search matrix

GSY = the same derivative evaluated at V = X + ETA * S

N = previously defined in Subroutine TASK

S(I) (I=1,N) = the Davidon search vector for an iteration . S = -(H * GX)

X(I) (I=1,N) = defined previously

SUBROUTINE CTERP - Continued

Output from block common includes

ALPHA = the scale factor for the downhill step vector SIG

FV = the value of the objective function at the interpolated minimum V

FZ = the same quantity, in another storage location

GV(I) (I=1,N) = the gradient of the objective function at the interpolated minimum V

P(I) (I=1,M) = the constraint vector at V

PEN = the penalty function at V, including the penalty coefficient PK

PV(I,J) (I=1,N; J=1,M) = the Jacobian of the constraint vector at V

SIG(I) (I=1,N) = ALPHA * S(I) , the step to the interpolated minimum

V(I) (I=1,N) = X(I) + SIG(I) , the interpolated minimum

SUBROUTINE FTERP

FTERP performs a one-dimensional minimization of a function of many variables using the Golden Section Technique to bracket a minimum on a given interval. It returns the interpolated minimum in the interval (X, X + ETA · S) . FTERP is called only if CTERP fails to estimate the relative minimum as it is the slower of the two routines. FTERP repeatedly calls subroutine RAKE to determine the objective function value at a given location.

The calling sequence is

```
     CALL FTERP(FUN,DER,PENF,PENFX)
```

where FUN, DER, PENF, and PENFX have been defined previously (see CTERP).

Input from block common includes

EP1 = PE2	= the convergence limit for the algorithm
ETA	previously defined
FX	previously defined
FY	previously defined
GSX	previously defined
GSY	previously defined
N	previously defined
R	= the Fibonacci ratio to the desired decimal place, .618 ... .
S(I) (I=1,N)	previously defined
X(I) (I=1,N)	previously defined

SUBROUTINE FTERP - Continued

Output from block common includes

ALPHA previously defined

FV previously defined

FZ previously defined

GV(I) (I=1,N) previously defined

KILL = the number of iterations of the golden section procedure; $5 \leq \text{KILL} \leq 50$

P(I) (I=1,N) previously defined

PEN previously defined

PV(I,J) (I=1,N; J=1,M) previously defined

SIG(I) (I=1,N) previously defined

V(I) (I=1,N) previously defined

SUBROUTINE RAKE

This subroutine is used to supply all values of the objective function and penalty function (and constraint vector) given the values of the variable angles X . It also generates gradient values for the objective function and penalty function. The subroutine is set up to allow for function calculation using the variable names of the calling routine. Subroutines called are FUN, DER, PENF, PENFX, and PENLTY.

The calling sequence is

```
     CALL RAKE(FUN,DER,PENF,PENFX,NCALL)
```

where RUN, DER, PENF, and PENFX have been defined (see ØTERP) and

NCALL = the entry point for RAKE. If = 1, this is the first call for function values in an optimization, and so the initial values of FX and PXN are found and the corresponding scale factors FSC and PK are calculated so that FX = PXN = 10., as long as FX ≥ 1. or PXN ≥ 1. FSC remains unchanged thereafter, and PK is multiplied by SCALE after each minimization.

Input from block common includes

FX = as input, the objective function value to be modified for the beginning of the next minimization to take into account the change in PK (the total FX value = (unmodified objective function FX) * FSC + PK * PXN)

GX(I) (I=1,N) = the same quantity for the gradient

PK previously defined

SUBROUTINE RAKE - Continued

PK2	= .5 * PK , used to calculate FI and FII
PXN	= the input quantity corresponding to FX above
PXNX	= the input quantity corresponding to FX above
V(I) (I=1,N)	previously defined
X(I) (I=1,N)	previously defined
XI(I) (I=1,N)	= a point at which the objective function is evaluated during Fibonacci (golden section) search
XII(I) (I=1,N)	= a point at which the objective function is evaluated during Fibonacci (golden section) search

Output from block common includes

FI	= objective function value at XI
FII	= objective function value at XII
FV	previously defined
FX	previously defined
GV	previously defined
GX	previously defined
P	previously defined
PEN	previously defined
PENX	= the gradient of PEN
PF	= previously defined
PK	previously defined
PV	previously defined
PX	previously defined
PXN	previously defined
PXNX	= the gradient of PXN

SUBROUTINE RAKE - Continued

VLAMBD(I) (I=1,M) = PK * P(I)

XLAMBD(I) (I=1,M) = PK * PF(I), should approach the Lagrange multiplier vector for a problem with equaltiy constraints PF(I) but no inequality constraints.

SUBROUTINE PENLTY

PENLTY calculates the penalty function value based on the constraint vector. It calls no subroutines.

The calling sequence is

```
     CALL PENLTY(PF,PX,XLAMBD,PXN,FX,PXNX,GX,PK)
```

where the parameters in the list correspond to definitions given previously. For some calls to PENLTY, the actual parameters may be P, PV, VLAMBD, PEN, FV, PENX, GV, and PK .

PF, PX, PK, and the unconstrained objective function and gradient FX and GX are input. FX and GX are output as (input FX) + PXN and (input GX) + PXNX, respectively, along with XLAMBD, PXN, and PXNX .

SUBROUTINE REPLCE

REPLCE stores a set of variables evaluated at the initial point of a search interval in the storage locations corresponding to the end point of the interval. It also performs the reverse of this procedure. It calls no subroutines.

The calling sequence is

```
     CALL REPLCE(NCALL)
```

where NCALL = 1 (input) means replace all variables from list 1 by those on list 2 and NCALL = 2 means replace all variables from list 2 by those on list 1 . All quantities are input/output through labelled common.

List 1: FX, PXN, X, GX, PXNX, PX, PF

List 2: FV, PEN, V, GV, PENX, PV, P

SUBROUTINE HBAD

HBAD modifies the Davidon variable metric matrix H for reintialization for the next minimization and may restore H to positive definiteness by zeroing off-diagonal elements and replacing diagonal elements by their absolute value. A positive definite matrix H satisfies

$X^{T}HX > 0$ for all non zero vectors X.

The calling sequence is

CALL HBAD(NCALL)

where NCALL = the entry for HBAD; specifying the array in which H is to be corrected. Presently, NCALL = 3 is used exclusively; here, H is set to the identity.

Input from block common includes

GSX	previously defined
H(I,J) (I=1,N; J=1,N)	previously defined
N	previously defined
YHDEN	= a quantity used to store information about the search direction at time of call to HBAD; not used at present

Output from block common includes

N(I,J) (I=1,N; J=1,N)	previously defined

SUBROUTINE MAB

MAB performs the matrix multiplication AB of two matrices A and B . It has two entry points MATB and MABT which calculate A^TB and AB^T respectively. (T denotes the transpose operation on a matrix). MAB is also utilized in the Intran overlay.

The calling sequences are

```
     CALL MAB(A,B,C,L,M,N,NRA,NRB,NRC)
```

or

```
     CALL MATB(...)
```

or

```
     CALL MABT(...)
```

where A(I,J) , B(I,J) (input) are arrays from which matrices are to be multiplied and C(I,J) (output) is the array in which the result is to be stored. A, B, and C have row dimensions NRS, NRB, and NRC, (input) respectively, and must be so dimensioned in the calling program. L, M, and N are the input dimensions of the matrices to be multiplied; the rule is that an LXM matrix times and MXN matrix yields an LXN matrix, regardless of whether these matrices are A or A- transpose or B or B- transpose. However, NRA and NRB are the true row-dimensions of the arrays A and B , respectively.

SUBROUTINE TRAC

TRAC provides optional output based on calculations made in Subroutine LYNX. This output provides information regarding the progress of the optimization procedure during the search for a constrained minimum of the objective function.

The output option is dependent on the value of IP which is user specified.

IP =

0 no output

1 write X, FX at every iteration

2 in addition, write one dimensional minimization data

3 write X, FX, PXN, PF

4 in addition, write GX, PXNX and one dimensional minimization data

5 in addition, write H at every iteration

6 write X, FX, and H at every iteration

7 write H at every iteration

8 write X, FX every iteration and attempted refinement data if successful

9 in addition, write PF, PXN every iteration

One dimensional minimization data includes the endpoint

V = X + ETA * S of the search interval

FY = FV objective function value

GSX, GSV one dimensional derivatives at X and V and the cosines of the angles between gradients GV, GX and the search vector S

SUBROUTINE TRAC - Continued

The calling sequence is

```
    CALL TRAC(NCALL)
```

where NCALL = the output mode parameter for TRAC. TRAC will output most of the quantities in block common, hence all block common corresponding to LYNX should be in TRAC.

PROGRAM INTERF

The purpose of INTERF is to detect and correct for visual interference between BOEMAN-I and his surrounding environment. In addition, physical interference between BOEMAN-I and the seatback is detectable. The detection process consists of finding intersections of line segments and bounded cockpit planes. For visual interference, the line segment used is that between the eye midpoint and the task defined eye aiming point; for physical interference, each link of BOEMAN-I plays the line segment role. On the other hand, all cockpit planes are tested in visual interference whereas only the seatback planes are considered for physical interference.

Correcting for visual interference consists of redefining the line of sight (with the eye aiming point fixed) so that it and the offending plane no longer intersect. If the correction procedure is not successful, the task is deemed infeasible. Visual interference is tested at the end of each task; physical interference with the seatback is tested at each step of the task. A discussion of the mathematical procedures used for the interference analysis appears in Section 3.4 of the Mathematical Model Document (D6-53620-2).

The entire interference procedure is embodied in PROGRAM INTERF and subroutines called are only for subsidiary calculations. INTERF is only called if the task is feasible.

Input variables set in previous overlays and transmitted through block common and stored in local variables include:

NPL = number of cockpit planes (NPLANE)

NVERT(I) = number of vertices of plane I, (N)

PPT(I,J,K) = coordinates I of plane K at vertex J,
(BOUND(I,J)) K = 1, NPLANE

*ETPT(I,J) = coordinates of eye aiming point (task defined)
(EFP(I)) I=1,3

RF(I,7) = eye midpoint (x, y, z) coordinates (EMP(I))
I = 1, 3

SWITCH = control indicator for whether visual interference or physical interference is to be checked

$$= \begin{cases} 0 & \text{check visual interference} \\ 1 & \text{check physical interference only} \end{cases}$$

*RG(I,J,K) = intermediate joint locations during the task
(SLINK(I,J)) I = 1, 3; J = 1, 26; (number of movable joints) K = position number

NSTEP = total number of steps in the task, (ISTEP)

'PPT(I,J,K), K = 29, 30, seat back planes, (SBOUND(I,J))
K = 29, 30

* Output from program to intermediate output tape

*LVOC(I,J) = link name I = 1, 3; J = 1, NL (Number of links)

*PDES(I,J) = name of cockpit plane I = 1, 4; J = 1, NPL
(Number of planes)

Those quantities calculated during the interference analysis or used as output are:

(Visual interference)

CENT(I) = centroid of plane K, I = 1, 3

LIGHT(I) = indicator of relationship between plane I and line of sight

LIGHT(I) =
-1 intersection point is not on line of sight
0 set upon entry to program
1 line of sight embedded in plane I
2 line of sight parallel to plane I
3 line of sight intersects plane I outside bounded region
4 line of sight intersects plane I inside bounded region
5 line of sight intersects plane I at eye aiming point

*SOLUT(I,J) = intersection point coordinates for plane J
(I = 1, 3)

NV(I) = number of vertices of plane K, K = 1, NPLANE

K7 = number of cockpit plane intersections at the end of a task

LOSMP(I) = midpoint of line of sight (I = 1, 3)

* Output from program to intermediate output tape.

BBOUND(I,J,K) = storage array for planes K for which interference has occurred, I = 1, 3, J = 1, number of vertices (NV(K))

*Q(I) = coordinates of point on redefined line of sight I = 1, 3

(Physical interference)

CEN(I) = centroid of seatback plane K (I = 1, 3), K = 29, 30

IGHT(I) = indicator of relationship between link K and seatback plane

IGHT(I) =
- 0 upon entry
- 6 link I intersects seatback plane outside plane boundary
- 7 link I intersects seatback plane inside plane boundary
- 8 link I intersects seatback plane at link end point
- 9 intersection point is beyond link I
- 11 link I imbedded in seatback plane
- 12 link I parallel to seatback plane

*N8 = link number for seatback interference

*SOL(I,J) = intersection point between link J and seatback plane (I = 1, 3)

* Output from program to intermediate output tape

SUBROUTINE INSECT

The purpose of subroutine INSECT is to discover if there is an intersection between the plane boundary line (an edge) and the centroid-intersection point line (lack of such an intersection implies the point of intersection is inside the bounded plane).

The calling sequence of INSECT is

CALL INSECT (S1, S2, S3, C, B11, B12, B13, B21, B22, B23, IND) where

$\left.\begin{matrix} S1 \\ S2 \\ S3 \end{matrix}\right\}$ = are coordinates point of intersection (SOL(I,J) or SOLUT(I,J), I = 1, 3; J fixed)

C = an array (of dimension 3) storing the centroid coordinates

$\left.\begin{matrix} B11 \\ B12 \\ B13 \end{matrix}\right\}$ = coordinates of a plane vertex (BOUND(I,J), SBOUND(I,J), I = 1, 3; J fixed)

$\left.\begin{matrix} B21 \\ B22 \\ B23 \end{matrix}\right\}$ = coordinates of the adjacent plane vertex (BOUND(I,J + 1), SBOUND(I,J + 1), I = 1, 3, J fixed)

$IND = \begin{cases} 0 & \text{no intersection} \\ 1 & \text{intersection has occurred between the two lines} \end{cases}$

All variables except IND are input to the subroutine.

SUBROUTINE DETi (i = 2, 3, 4)

The purpose of DETi (i = 2, 3, 4) is to calculate the value of a determinant of order i. The method used is the repeated application of Laplace expansion. The general calling sequence for DETi (i = 2, 3, 4) is

CALL DETi (Ajk, F) where j = 1, i; k = 1, i; i = 2, 3, 4 and k varies most often, and

Ajk = element in j^th row and k^th column of determinant of order i, (input)

F = value of determinant of order i

PROGRAM SUMM

Program SUMM is called by the main overlay of the computer program for each task performed, **that task** is feasible. The following quantities are calculated:

1.	TD	Linear displacement of each joint per task
2.	TMD	Linear displacement of each mass centroid
3.	CTD	Cumulative summation of linear displacement for each joint
4.	CTMD	Cumulative summation of mass centroid displacement for each link
5.	WORK	Work for each link per task
6.	CWORK	Cumulative summation of work for each link
7.	SMASS	Total mass of man
8.	SCTD	Total joint displacement for task
9.	SWORK	Total work of all link per task
10.	DJA	PSI deflection (twist) per link per task
11.	CDJA	Cumulative summation of PSI deflection for each link
12.	DHD	Head Deflection
13.	DI	Eye Deflection
14.	CDHD	Cumulative summation of head deflection
15.	CDI	Cumulative summation of eye deflection

The program accepts input through labeled common from other overlays. The necessary input includes initial and final positions of all joints, the per cent of the link length for centroid location, parameters defining link structure of man-model, mass values for each link, and Euler angles for each link. The output is written onto the intermediate output file for later processing in the output overlay.

The subroutine called by SUMM is Subroutine **CMLØC**

Input to SUMM via block common includes

ANGLE1 - initial Euler angle array

ANGLE2 - terminal Euler angle array

R - array of initial joint locations

RF - array of terminal joint locations

MASS - array of masses for each link

LINKS - array of link lengths

CPCT - array of percentages of link length for centroid location

SUBROUTINE CMLØC

CMLØC calculates the initial and final mass centroid location given initial and final joint locations and the location of the centroid relative to the proximal end of the link.

The calling sequence for CMLØC is

CALL CMLØC (R, RF, J, JM1, CPCT, II, CLØC, CLØCF)

DIMENSION R(3, NL), RF(3, NL), CPCT(NL), CLOC(3, NL), CLØCF(3, NL) where

R - array of initial joint locations, (input)

RF - array of final joint locations, (input)

J - particular link number (joint number, top of link), (input)

JM1 - previous joint number for particular link

CPCT - array of percentages referencing length along link where mass centroid is located, (input)

II - index to determine particular link, (input)

CLØC - initial mass centroid location, (output)

CLØCF - final mass centroid location, (output)

PROGRAM ØUTGØ

ØUTGØ is the output overlay. It accepts the intermediate output file written by previous overlays and a separate binary file which stores intermediate position and orientation data written by the MAN1 overlay. The output is in tabular form and covers three broad areas: input data, task processing information and summation. The tables which are largely self-explanatory, provide a history of BOEMAN-I's performance and are arranged by task. The summation area is given for each computed (feasible) task and provides cumulative totals from the starting position. For feasible tasks, BOEMAN-I's initial and final position are printed. If the task is infeasible, all intermediate positions are printed, up to the point of infeasibility.

All output is written onto the output file as well as a backup tape which stores duplicate printer information. This backup tape is used for chart and graph information as well as for duplication copies of the printout, if necessary.

Control parameters of the form KTi (i = 1, ---, 20) are used to provide various output options for the user which may abbreviate the total number of output pages or tables.

The program is self-contained and calls no subroutines.

Input variables to ØUTGØ transmitted via block common include:

KTi, i = 1, 20 control parameters referencing printout options

NCC = number of control codes

NPL = number of cockpit planes

NVERT(I) = number of vertices of the Ith cockpit plane

All other input variables are read from the intermediate output tape and the MAN1 output tape. This overlay is called after all tasks have been processed and all of the input variables are written on the printer and backup tape.

Appendix VII

Validation Program and Subroutine Descriptions

Program SVØMM

This program accepts joint location data ("N" coordinates) of humans at midpath during a task. Each task is repeated "NR" times and an average location results. This is then compared with the same sized BOEMAN-I for the same task at its corresponding midpath location. In each case, the joint coordinates are determined using a cutting plane through the path.

An F-statistic is used to test the hypothesis that there is no significant difference between the paths of motion of BOEMAN-I and humans in performance of the task (i.e they belong to the same population). Using the formula for the F-value

$$F = \frac{NR*(NR-N)}{N*(NR-1)} \sum_{\substack{I=1 \\ J=1}}^{N} (XM(I) - SXM(I)) \cdot \left[C\emptyset V[X] \right]^{-1}_{IJ}$$

where

$$\left[C\emptyset V[X] \right]_{IJ} = \frac{1}{NR-1} \left[(X(I,K) - XM(I))*(X(J,K)-XM(J)) \right]_{(IxJ)}$$

for all I=1,N, J=1,N, K=1,NR

And the degrees of freedom are given as

M = NR-N and N

Figure 11 contains a general flow diagram of Program SVØMM.

Input for the program includes

CØDE = a control to allow for sequential processing
=HYPØ {= PRØBLM process following data
{≠ PRØBLM stop
PN = descriptive title of data set
N = number of joint coordinates being compared
NR = number of repetitions of the path
MX = maximum order of covariance matrix

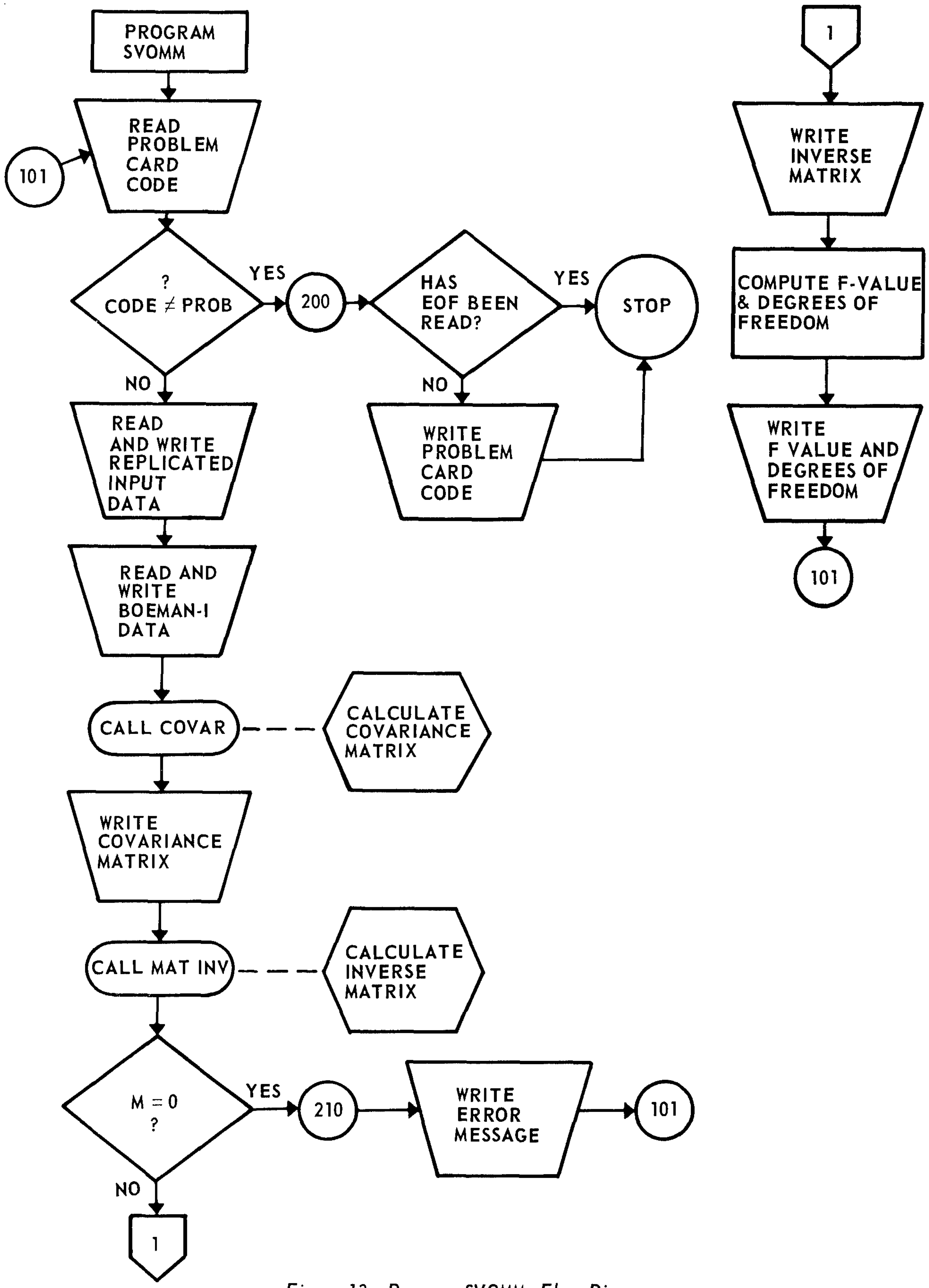


Figure 12. Program SVOMM–Flow Diagram

INP { = output control to print out input data
= 1 printout data; $\neq$ 1 suppress data printout

FMT = format statement number allowing for input of data of various accuracies

X(I,J) = replicated joint location data (one coordinate only) I=1, N, J=1, NR

SXM(I) = BOEMAN-I joint location data (one coordinate only) I=1, N

Output data includes

PN = problem description

X(I,J) = replicated joint location data (one coordinate only) J=1,N J=1, NR

SXM(I) = BOEMAN-I joint location data (one coordinate only) I=1, N

A(I,J) = covariance matrix of replicated data I,J=1,N

AI(I,J) = inverse of covariance matrix I,J=1, N

FV = F value (computed)

N = number of joint coordinates being compared; (degree of freedom)

M = difference between number of replications and number of compared coordinates

A check is made to insure that computation of the inverse matrix does not yield singularity.

Subroutine CØVAR

The purpose of CØVAR is to calculate a covariance matrix using the input data of replicated joint locations for each path or task. The matrix is calculated using

$$XM(I) = \sum_{J=1}^{NR} X(I,J)/NR$$

$$RNN = \frac{1}{(NR-1)}$$

$$SA(I,J) = RNN*\sum_{K=1}^{NR} (X(I,K)-XM(I))*(X(J,K)-XM(J)); \quad I,J=1,N$$

where XM is the input data means; RNN is the reciprocal of the number of replications minus one; and SA is the covariance matrix.

The calling sequence for CØVAR is

CALL CØVAR(NR,NT,X,XM,SA)

where

NR = number of repetitions of path (input)

NT = number of joint coordinates being compared (input)

X(I,J) = array storing replicated joint locations (one coordinate only) (input) I=1,NR J=1,NR

XM(I) = means of χ array I=1,NT (output)

SA(I,J) = covariance array I,J=1,NT (output)

Subroutine MATINV

This subroutine finds the inverse of a non-singular NXN matrix. The method uses the Gaussian elimination technique with pivoting of the diagonal elements on both the original matrix and the identity matrix. A check for singularity is also performed.

The calling sequence for MATINV is

```
CALL MATINV (SA,AI,N,NR,M)
```

where

SA(I,J)	=	matrix to be inverted (I,J=1,N)	(input)
AI(I,J)	=	inverse matrix (I,J=1,N)	(output)
N	=	number of rows and columns of SA and AI	(input)
NR	=	maximum number of rows of input matrix	(input)
M	=	output indicator for singularity of input matrix	
		$M \begin{cases} = 0 & \text{SA is singular} \\ \neq 0 & \text{SA is non-singular} \end{cases}$	(output)

Appendix VIII

Multi-mission Simulator Control

Code Definitions

MULTIMISSION SIMULATOR CONTROL CODE LISTING

(Identifies centroid unless specified otherwise)

Flight Controls (FC)

(1)	FCFWS	Flap/Wing sweep control (primary)
(2)	FCEPS	Emergency flap switch
(3)	FCRT	Electrical control (rudder trim)
(4)	FCEPT	Electrical control (emergency pitch trim)
(5)	FCCSC	Center stick control
(6)	FCSPS	Speed brake switch
(7)	FCT	Throttles

Flight Instruments (FI)

(1)	FIRPML	Engine display (left % RPM)
(2)	FIRPMR	Engine display (right % RPM)
(3)	FIPT	Pitch/trim
(4)	FIAT	Aileron trim
(5)	FIWSFP	Wing sweep/flap position
(6)	FIFT	Total fuel
(7)	FIFI	Digital fuel (panel centroid)
(8)	FITSI	Turn and slip indicator
(9)	FIAAT	Angle of attack (tolerance indicator)
(10)	FIAAA	Angle of attack (analog)
(11)	FIHUC	Head-Up Display Control (center)
(12)	FIHUD	Head-Up Display (screen center)
(13)	FIAI	Attitude Indicator
(14)	FIAS	Airspeed
(15)	FIMM	Machmeter
(16)	FIVSD	VSD (Vertical Situation Display) centroid
(17)	FIVSDSS	VSD Symbol Selector (upper left corner)
(18)	FIVSDH	VSD horizon selector (upper right)
(19)	FIVSDI	VSD intensity/contrast (lower right)
(20)	FIVSDC	VSD switch (lower left)
(21)	FIC	Clock
(22)	FIBA	Barometric altimeter
(23)	FIRA	Radar Altimeter
(24)	FIMC	Magnetic compass
(25)	FIRC	Rate of climb
(26)	FIGM	G-meter
(27)	FIRMI	RMI (Radio magnetic indicator)
(28)	FIHSD(1)	HSD (horizontal situation display)
(29)	FIHSD(2)	HSD (extreme bottom point on screen)
(30)	FIHSDGC	HSD (gain/contrast selector)
(31)	FIHSDCI	HSD (chart intensity selector)

Automatic Flight Control (AFC)

(1)	AFCSCP	AFC System control panel
(2)	AFCSSP	Steering select panel
(3)	AFCSAP	Stability augmentation panel
(4)	AFCADC	Air data command control panel

Mechanical Systems (MS)

(1)	MSESP	Engine start panel
(2)	MSEPS	Elec Control panel - external power switch
(3)	MSLCI	Lights control - internal
(4)	MSLCE	Lights control - external
(5)	MSLGC	Landing gear control
(6)	MSFMP	Fuel management panel
(7)	MSECP	Environment control panel
(8)	MSCPI	Cabin pressure altitude gage
(9)	MSLØQ	Liquid Oxygen quantity gage
(10)	MSHP	Hydraulic panel (utility power control)
(11)	MSAHC	Arresting hook control
(12)	MSRAT	Ram air turbine (RAT) handle
(13)	MSEBI	Emergency brake indicator
(14)	MSMLS	Master light switch
(15)	MSAS	Anti-skid

Defense/Countermeasure (DCM)

(1)	DCMSCP	Defense System Control Panel
(2)	DCMRHAWI	RHAW (Radar Homing and Warning) operation indicator
(3)	DCMLWI	Launch Warning Indicator
(4)	DCMEDSP	Electronic Defensive Status (EDS) panel

Advisory and Caution Annunciator (ACA)

(1)	ACAMC	Master caution (reset)
(2)	ACAEFL	Engine (1) fire
(3)	ACAEFR	Engine (2) fire
(4)	ACALP	Light panel (ACA panel)
(5)	ACALFW	Low fuel
(6)	ACAWW	Wheels
(7)	ACALAW	Low altitude warning

Weapon System (WS)

(1)	WSAIS	Weapon monitor and select - aim interlock switch
(2)	WSMP	Weapon management panel (centroid)
(3)	WSASP	Attack select panel
(4)	WSMAS	Master arm switch
(5)	WSGS	Gun switch
(6)	WSWS	Weapon status
(7)	WSSPS	Special weapon control switch
(8)	WSSPAI	Special weapon arm indicator
(9)	WSEJ	Emergency jettison
(10)	WSLLLTV	LLLTV - Laser control panel

Communication, Navigation and Identification (CNI)

(1)	CNIMPS	Integrated CNI Control Panel (master power switch)
(2)	CNIMSS	Integrated CNI Control Panel (MIC selector switch)
(3)	CNITS	Integrated CNI Control Panel (transceiver selector)
(4)	CNIICSP	ICS control panel
(5)	CNIRBC	Radar beacon control panel
(6)	CNIDLR	Data link readout
(7)	CNIDLC	Data link command
(8)	CNINMS	Navigation control panel _NAV mode selector
(9)	CNILØS	Navigation Control Panel - LORAN Operate Switch
(10)	CNIDSS	Navigation Control Panel - Destination select switch
(11)	CNINDP	Navigation display panel
(12)	CNIHTTD	Heading and TTD (time to destination) switch
(13)	CNIMDS	Map and data storage locker

Appendix IX

FORTRAN IV SUBROUTINE MINUM (MA-077)

SUBJECT FORTRAN II, IV Subroutines MINUM

PURPOSE:

The subroutine MINUM determines the minimum value of a function of several parameters. This optimization technique is applicable to a more general class of problems than many of the existing optimization subroutines. The function (1) may have discontinuities, (2) may have several relative minima and (3) need not be differentiable.

METHOD:

A complete description of the algorithm for MINUM is given in Ref. 1. Only a brief outline of the computational technique is given here.

The minimum value of a function is determined by evaluating the function for many values of the parameters (parameters must be in 0-1 interval). The following four methods are used to change the parameter values.

(1) a gradient step (GR) or a boundary gradient step (BG)

(2) a random direction step (RD). If this step is unsuccessful, a step in the opposite direction will be taken (ND)

(3) an average direction step (AV). The direction for this step is the average of the directions for the last five successful tries.

(4) a jump step (JS). The values of the parameter are random numbers.

The step size for steps 1 to 3 is dependent on the number of successes and failures in previous steps. The relative frequencies for each of these 4 steps is specified by the user.

DISCUSSION:

Several applications for this subroutine and the construction of the merit function are discussed in Ref. 1. Some simple examples are presented here.

Example 1 - Step Function

The merit function for this example is the step function given by

$$F(x_1,x_2) = \begin{cases} 0 & \text{if} \quad .9 \leq x_1 \quad \text{and} \\ & \qquad .5 \leq x_2 \leq .7 \\ 1 & \text{otherwise} \end{cases}$$

This function is illustrated in Fig. 1.

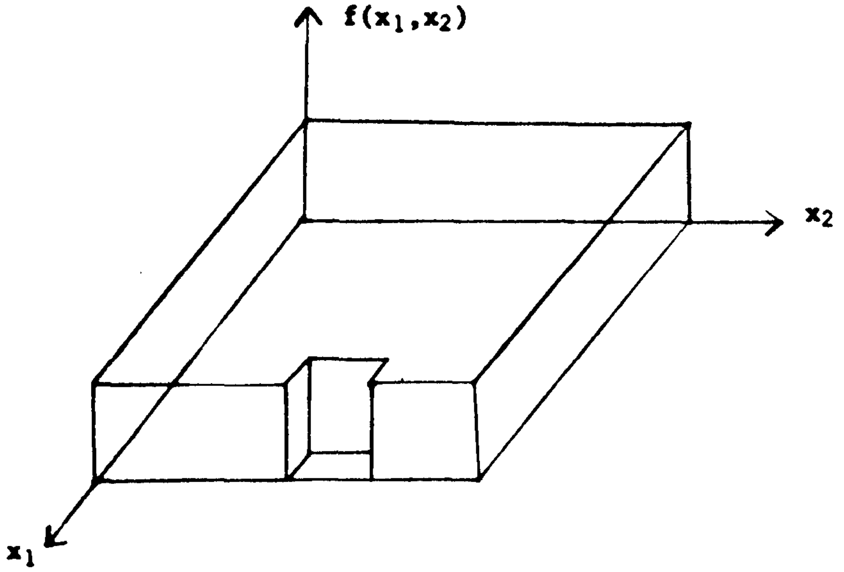


FIGURE 1
Merit Function for Ex. 1

For this example only jump steps were requested. The other 3 types of steps all require longer computation times and could not be expected to decrease the number of steps required. The gradient step is the least desirable step for this type of function. When a gradient step is requested where the function is constant in the neighborhood of the current position, the function is evaluated n (no. of parameters) times, a test is made, the gradient step is abandoned, and another type of step is tried.

The total number of steps requested for this problem was 200 and the minimum was found for the first time on step 108. The 200 points, (x_1,x_2), where the function was evaluated by MINUM are shown in Fig. 2.

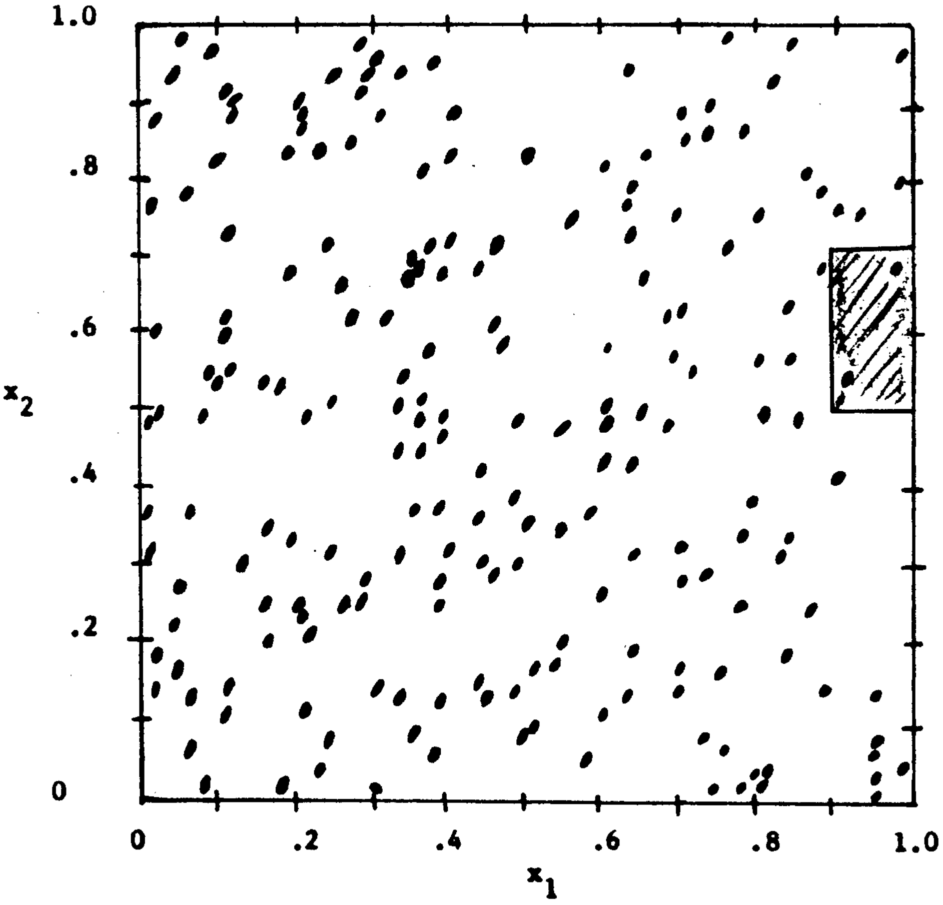


FIGURE 2

Function Evaluation - Ex. 1

The probability of finding the minimum for this particular function on a single step is $Pr = (.1)(.2) = .02$. Thus, in 200 steps the average number of times the point (x_1,x_2) will be in the minimum region is 4 .

The probability of finding the minimum for this type of function will decrease as the number of parameters increases. For a function of 10 parameters, where the sides of the minimum region have length .5 , the probability of finding the minimum on a single step is $(.5)^{10} = .001$. Thus, on the average, only one step in 1000 will fall in the minimum region for this function. This demonstrates the importance of defining the parameters so only the region of interest is searched.

Example 2 - Exponential-Cosine Function

The merit function for this example is

$$f(r) = e^{-2r} \cos (6\pi r)$$

where the radius r is $\sqrt{x_1^2 + x_2^2}$. This function is illustrated in Fig. 3. A summary of the printout from MINUM is given in Table 1 for the first 90 steps. The radii at which the function was evaluated in these 90 steps are indicated in Fig. 3.

Some of the search characteristics exhibited in Table 1 are typical for MINUM.

(a) The relative frequency of random direction steps will always be greater than requested (except for the case when the requested frequency is zero). The requested relative frequencies for this example were 12.5%, 37.5%, 25% and 25% for RD, GR, AV and JS steps

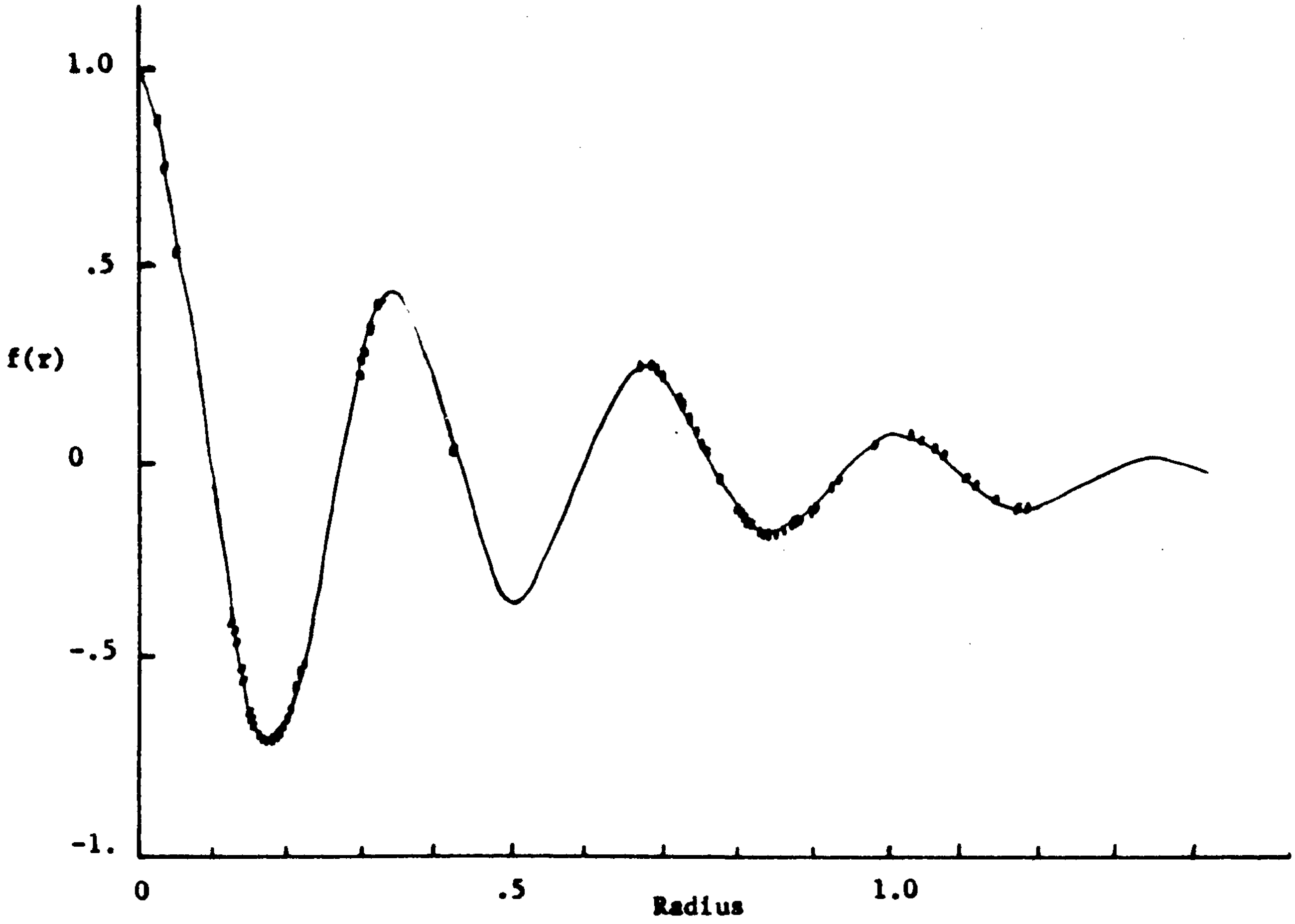


Figure 3

Merit Function - Ex. 2

Step No.	Step Type	Current F	Radius	Best F
1	RD	-.014	1.090	-.014
	RD	-.063	1.116	-.063
	RD	-.097	1.160	-.097
	RD	-.032	1.099	
5	AV	-.032	1.099	
	RD	.097	1.156	
	ND	.115	1.025	
	JS	-.162	.857	-.162
	AV	-.177	.808	-.177
10	AV	-.119	.782	
	GR	.254	.677	
	AV	-.119	.782	
	RD	-.072	.893	
	ND	.038	.741	
15	RD	.066	.940	
	ND	.249	.680	
	RD	.083	.730	
	ND	-.046	.902	
	RD	.260	.671	
20	ND	-.167	.854	
	RD	-.166	.855	
	ND	-.047	.761	
	RD	-.190	.830	-.190
	RD	-.166	.855	
25	AV	-.186	.818	
	GR	-.124	.784	
	RD	-.181	.812	
	ND	-.172	.851	
	RD	-.152	.775	
30	ND	-.141	.868	
	RD	-.130	.872	
	ND	-.140	.790	
	RD	-.121	.876	
	ND	-.129	.786	
35	JS	-.719	.157	-.719
	RD	.416	.295	
	ND	.533	.050	
	AV	.346	.285	
	JS	-.179	.846	
40	JS	.026	.414	
	GR	.892	.020	
	JS	-.097	1.155	
	RD	.233	.272	
	ND	-.551	.125	
45	RD	.270	.276	
46	ND	-.458	.116	
	RD	-.410	.112	
	ND	.285	.278	
	RD	.865	.023	
50	ND	.435	.298	
	RD	-.679	.143	
	ND	-.661	.183	
	AV	-.562	.198	
	GR	-.392	.110	
55	RD	-.701	.174	
	ND	-.715	.155	
	JS	.107	.725	
	RD	-.578	.196	
	ND	-.556	.126	
60	JS	.264	.656	
	JS	.098	1.036	
	JS	-.126	.874	
	RD	-.527	.202	
	ND	-.451	.115	
65	AV	-.709	.170	
	JS	.048	1.061	
	GR	-.673	.142	
	RD	-.714	.168	
	ND	-.697	.148	
70	JS	-.097	1.158	
	JS	.061	1.302	
	RD	-.719	.157	
	ND	-.720	.159	-.7200
	ND	-.720	.162	-.7204
75	ND	-.716	.167	
	RD	-.692	.146	
	ND	-.685	.178	
	AV	-.700	.174	
	JS	.049	.739	
80	GR	-.693	.146	
	RD	-.721	.161	-.7206
	RD	-.720	.161	
	AV	-.701	.173	
	GR	-.688	.145	
85	RD	-.720	.160	
	ND	-.720	.164	
	RD	-.692	.146	
	ND	-.693	.176	
	JS	.131	.719	
90	RD	-.700	.174	

TABLE 1

MINUM Results for Exponential Cosine Function respectively. The observed frequencies for these 4 types of steps were 69%, 6.5%, 9% and 15.5% after 200 steps.

(b) Unless the region of the minimum is large, the random direction steps will be more successful than the gradient steps at the beginning of the search. The step length is always the maximum length at the start of the search and the gradient steps tend to overshoot the relative minima. When there are many successive unsuccessful steps, the step length will be decreased and the gradient step will be more successful.

(c) During the initial steps the average direction steps are usually as successful as the random direction steps. The directions for the last five successful steps are used to determine the direction for this step and since the successful steps initially occur in different regions, the average direction is usually not an optimum direction.

(d) After the initial steps a random direction step (RD) is nearly always followed by a negative direction step (ND). This in part accounts for the higher observed relative frequencies for the random direction step.

For most applications, little will be known about the merit function and thus it will usually be difficult to determine how to reduce the number of steps required for finding a minimum. This is not a problem for the cases where the merit function is easily evaluated. However, in the cases where the number of parameters is large and where the evaluation of the merit function requires a long computer time, it is desirable to use MINUM as efficiently as possible. For these cases only the region of interest for each parameter should be transformed to the 0-1 interval. It will usually be difficult to determine the relative frequencies for the 4 types of steps which will provide the most efficient search. However, a careful examination of the step-by-step behavior of MINUM will in any times provide the information needed to improve the choice of the relative frequencies.

```
USAGE:   DIMENSION   PARM(N),A(7*N)

         CALL MINUM (N,PARM,A,FUN,IU,IX,ISTP,IPRINT,JR,JG,JA,JJ)
```

INPUTS: N - no. of parameters

PARM(I) - array of starting values for parameters. Must be between 0. and 1. .

A - array for working storage. Must have size at least 7*N.

FUN - name of function to be minimized (requires EXTERNAL card in calling program.)

IU - start multiplier for random no. generator RAND. IU must be odd.

IX - fixed multiplier for random no. generator. IX must be = 8n ± 3 where n is an arbitrary integer and IX should be near 2**X where X = 17.5 for the 7094 and X = 24 for the 6600.

ISTP - total no. of steps to be tried

IPRINT - modulus of steps when printing desired. If IPRINT is negative the history information is suppressed.

JR - unnormalized frequency of use of random steps.

JG - unnormalized frequency of use of gradient steps

JA - unnormalized frequency of use of average steps

JJ - unnormalized frequency of use of jump steps

OUTPUTS:

PARM(I) - the values of the parameters which gave the best minimum

IU - final value of random no. multiplier

PRINTED OUTPUT:

The subroutine MINUM prints intermediate values of the parameters and the corresponding function value. The initial values are always printed. Each IPRINT steps MINUM will print the following information.

(1) No. of steps taken

(2) Current value of best minimum

(3) Values of parameters for best minimum

(4) Current step size.

If the history information has not been suppressed (IPRINT > 0), the following information is also printed each IPRINT steps.

(1) the current parameter values

(2) the current function value

(3) the current type step

(4) the no. of successful and the no. of unsuccessful trials for each of the 4 types of step

(5) the total successful distance for each the average, random direction, and gradient steps.

(6) the direction cosines for current step (if not jumpstep)

After the final step the value of the current best minimum and the corresponding parameter values are printed.

SUBPROGRAMS:

Subroutine RAND - PS419,PS-419A Function FUN which evaluates function to be minimized.

ERROR RETURN:

None

RESTRICTIONS:

MINUM may be used for several purposes in one program only if calls to MINUM are made serially. Nested calls to MINUM (i.e., MINUM calls FUN which in turn calls MINUM to evaluate function) are not allowed.

SAMPLE PROBLEM:

The source program and the printout for the circuit design problem described in Ref. 1 are given here. Two runs were made, each having different initial values. The 6600 central processor time was 3.1 sec. for each run.

```
          FORTRAN IV PROGRAM MZZY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
          C
          C  MAIN PROGRAM FOR MINUM TEST PROBLEM 2
          C
000043          DIMENSION X(4),TEMP(28)
000043          COMMON HPI,PI,TWOPI,THETA(10)
000043    F     FSS
000043          PI=3.1415926536
000045          HPI= PI/2.
000047          TWOPI= 2.*PI
000050          N=4
000051          IU=3746531
000052          IX=16777213
000054        5 FORMAT(6I10)
000054       10 FORMAT(6F10.0)
000054          READ(5,5)  NCASE
000061          DO 999  IJK=1,NCASE
000063      100 READ(5,5)  IPRINT,ISTEPS
000072          READ(5,5)  JR,JG,JA,JJ
000105          READ(5,10) A1,B1,A2,B2
000120          X(1) = 1./(1.+A1)
000123          X(2) = 1./(1.+B1)
000126          X(3) = 1./(1.+A2)
000130          X(4) = 1./(1.+B2)
000133          DM=FSS(X)
000135          WRITE(6,903) (THETA(I),I=1,10),A1,B1,A2,B2
000156          CALL MINUM(N,X,TEMP,FSS,IU,IX,ISTEPS,IPRINT,JR,JG,JA,JJ)
000170          DM=FSS(X)
000173          A1= 1./X(1) -1.
000175          B1= 1./X(2) -1.
000177          A2= 1./X(3) -1.
000201          B2= 1./X(4) -1.
000203          WRITE(6,901)  DM
000210      901 FORMAT(1H1,11HBEST MIN = ,E20.10)
000210      900 FORMAT(1H-,10X,6HTHETAS/1H ,10F12.4/1H-,10X,2HA1,18X,2HB1,18X,2HA2
               Z,18X,2HB2/4E20.7)
000210      903 FORMAT(1H1,10X,6HTHETAS/1H ,10F12.4/1H-,10X,2HA1,18X,2HB1,18X,2HA2
               Z,18X,2HB2/4E20.7)
000210      999 WRITE(6,900) (THETA(I),I=1,10),A1,B1,A2,B2
000234          STOP
000235          END
```

```
                                    FORTRAN IV FUNCTION FSS(X)
000417           DIMENSION X(4),FNM(2),DEN(2),ALF(2)
000417           COMMON  HPI,PI,TWOPI,THETA(10)
000417           FSS =0.
000420           DO 100  N=1,10
000421           FN=N
000422           FNM(1)= FN*(1.-1./X(1))
000425           DEN(1)= 1./X(2) - 1. -FN*FN
000431           FNM(2)= FN*(1.-1./X(3))
000434           DEN(2)= 1./X(4) -1. -FN*FN
          C
          C   COMPUTE   ALF(I)  SO THAT BETWEEN  0   AND TWOPI
          C
000437           DO 50 I=1,2
000441           IF(DFN(I)) 10,2,1
000443         1 IF(FNM(I)) 20,21,21
000446         2 IF(FNM(I))  30,31,32
000451        10 ALF(I)=PI +ATAN(FNM(I)/DEN(I))
000461           GO TO 50
000461        20 ALF(I)=TWOPI + ATAN(FNM(I)/DEN(I))
000471           GO TO 50
000471        21 ALF(I)= ATAN(FNM(I)/DEN(I))
000500           GO TO 50
000500        30 ALF(I) = TWOPI-HPI
000503           GO TO 50
000504        31 ALF(I)=0.
000506           GO TO 50
000506        32 ALF(I)=HPI
000510        50 CONTINUE
000512           THETA(N)= (ALF(1)+ALF(2))*2.
000516        60 IF(THETA(N)+FN.LF.PI)  GO TO 100
000522           THETA(N)=THETA(N)-TWOPI
000525           GO TO 60
000525       100 FSS=FSS+(11.-FN)*ABS(THETA(N)+FN)
000537           RETURN
000540           END
```

```
                                                         SAMPLE    PUT 1

     THETAS
-1.0134    -2.0000     -2.9702     -3.9679     -5.0219     -6.0739     -6.9996     -7.7360     -8.3033     -8.7454
     A1                   B1                   A2                   B2
1.3840000E+01        3.8510000E+01        5.8100000E+00        3.8600000E+01


STARTIN. MINIMUM=   45.411894E-01  AT
 67.385445E-03  25.310048E-03  14.684288E-02  25.252525E-03

FREQUENCIES=  20 RANDOM   60 GRADIENT   20 AVERAGE   20 JUMP


BEST MINIMUM =  45.411894E-01 AFTER          20 STEPS (CURRENT STEP SIZE  66.666667E-03)
BEST POSITION .06738544 .02531005 .14684288 .02525253
        RD            GD            AD            JS        RATIO        MINIMUM        RD          BD          AD
RD     0/     13     0/     2     0/     0     0/     5    .3333 66.464855E+00  0.          0.          0.
DIR COS    -.2870    -.6356    -.4919    -.5213
CURRENT POSITION
     .04825467      .01706156      .11405213      .00950192

BEST MINIMUM =  45.411894E-01 AFTER          40 STEPS (CURRENT STEP SIZE  22.222222E-03)
BEST POSITION .06738544 .02531005 .14684288 .02525253
        RD            GD            AD            JS        RATIO        MINIMUM        RD          BD          AD
ND     0/     28     0/     3     0/     0     0/     9    .3333 63.017430E+00  0.          0.          0.
DIR COS     .0415    -.0406     .7652    -.6412
CURRENT POSITION
     .06830844      .02440712      .16384642      .01100333

BEST MINIMUM =  45.411894E-01 AFTER          60 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .06738544 .02531005 .14684288 .02525253
        RD            GD            AD            JS        RATIO        MINIMUM        RD          BD          AD
GR     0/     42     0/     5     0/     0     0/    13    .3333 12.053036E+00  0.          0.          0.
DIR COS    -.0846    -.5785    -.0314    -.8107
CURRENT POSITION
     .06717663      .02388168      .14676531      .02325083

BEST MINIMUM =  45.411894E-01 AFTER          80 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .06738544 .02531005 .14684288 .02525253
        RD            GD            AD            JS        RATIO        MINIMUM        RD          BD          AD
RD     0/     59     0/     6     0/     0     0/    15    .3333 46.634411E-01  0.          0.          0.
DIR COS    -.6014     .0029    -.7591    -.2491
CURRENT POSITION
     .06689047      .02531240      .14621808      .02504752
```

```
BEST MINIMUM =  45.411894E-01 AFTER        100 STEPS (CURRFNT STEP SIZF  91.449474E-06)
BEST POSITION .06738544 .02531005 .14684288 .02525253
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
RD     0/    75      0/     7      0/     0      0/    18    .3333 45.670527E-01  0.           0.           0.
DIR COS    .0552     .0463     .8422    -.5343
CURRENT POSITION
     .06739049      .02531428      .14691990      .02520367

BEST MINIMUM =  45.381896E-01 AFTER        120 STEPS (CURRENT STEP SIZE  30.483158E-06)
BEST POSITION .06741421 .02532639 .14689364 .02524581
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
RD     2/    90      0/     9      0/     0      0/    21   0.      45.381896E-01 60.966E-06  0.           0.
DIR COS    .4719     .2681     .8327    -.1101

BEST MINIMUM =  45.374176E-01 AFTER        140 STEPS (CURRENT STEP SIZE  10.161053E-06)
BEST POSITION .06742453 .02534368 .14691746 .02524143
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
GR     3/   104      1/    11      0/     2      0/    23   0.      45.374176E-01 91.449E-06 10.161E-06  0.
DIR COS   -.4007     .8975    -.1542    -.1009

BEST MINIMUM =  45.208649E-01 AFTER        160 STEPS (CURRENT STEP SIZE  27.436842E-05)
BEST POSITION .06817660 .02599096 .14835271 .02502800
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
AV     3/   104      1/    12     19/    21      0/    23   0.      45.208649E-01 91.449E-06 10.161E-06 17.579E-04
DIR COS    .4278     .3682     .8165    -.1214

BEST MINIMUM =  44.398371E-01 AFTER        180 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .07005461 .02760728 .15193668 .02449503
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
RD     3/   113      1/    13     25/    30      0/    24    .3333 48.019000E-01 91.449E-06 10.161E-06 61.474E-04
DIR COS   -.3696    -.3006     .1761     .8614
CURRENT POSITION
     .06975042      .02735986      .15208159      .02520401

BEST MINIMUM =  44.342618E-01 AFTER        200 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .06994940 .02729060 .15118440 .02450610
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
RD     4/   127      1/    15     25/    31      0/    27    .3333 48.477990E-01 91.449E-05 10.161E-06 61.474E-04
DIR COS    .9156    -.0462    -.0313    -.3983
CURRENT POSITION
     .07070295      .02725258      .15115866      .02417829

BEST MINIMUM =  43.777940E-01 AFTER        220 STEPS (CURRENT STEP SIZE  27.436842E-05)
BEST POSITION .07017109 .02715750 .15119294 .02462818
       RD            GD            AD            JS       RATIO          MINIMUM        RD           GD           AD
RD     6/   141      1/    17     25/    34      0/    28    .3333 44.962856E-01 91.449E-05 10.161E-06 61.474E-04
DIR COS    .1048     .3715    -.7557     .5291
CURRENT POSITION
     .07019985      .02725941      .15098562      .02477334
```

```
BEST MINIMUM =  43.777940E-01 AFTER        240 STEPS (CURRENT STEP SIZE  30.483158E-06)
BEST POSITION .07017109 .02715750 .15119294 .02462818
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
ND      6/   156      1/    18    25/     35      0/     31    .3333 43.898877E-01 91.449E-05 10.161E-06 61.474E-04
DIR COS    .2928     .0155     .0561     .9544
CURRENT POSITION
     .07018002      .02715797      .15119465      .02465728

BEST MINIMUM =  43.774661E-01 AFTER        260 STEPS (CURRENT STEP SIZE  10.161053E-06)
BEST POSITION .07016556 .02715481 .15118816 .02463470
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
ND      7/   169      1/    20    25/     37      0/     34    .3333 43.811910E-01 91.449E-05 10.161E-06 61.474E-04
DIR COS   -.5447    -.2650    -.4704     .6418
CURRENT POSITION
     .07016002      .02715212      .15118338      .02464122

BEST MINIMUM =  43.741790E-01 AFTER        280 STEPS (CURRENT STEP SIZE  30.483158E-06)
BEST POSITION .07022206 .02719214 .15127620 .02462220
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
ND      7/   177      1/    21    32/     46      0/     36    .3333 43.769395E-01 91.449E-05 10.161E-06 62.592E-04
DIR COS    .1191     .8748     .2324    -.4081
CURRENT POSITION
     .07022569      .02721881      .15128328      .02460976

BEST MINIMUM =  43.741790E-01 AFTER        300 STEPS (CURRENT STEP SIZE  33.870176E-07)
BEST POSITION .07022206 .02719214 .15127620 .02462220
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
ND      7/   189      1/    23    32/     48      0/     40    .3333 43.747583E-01 91.449E-05 10.161E-06 62.592E-04
DIR COS   -.7432     .2793     .4587    -.3990
CURRENT POSITION
     .07021954      .02719309      .15127775      .02462085

BEST MINIMUM =  43.740192E-01 AFTER        320 STEPS (CURRENT STEP SIZE  11.290059E-07)
BEST POSITION .07021628 .02718933 .15127455 .02462358
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
JS      9/   201      1/    25    32/     50      0/     44    .3333 10.484930E+01 91.449E-05 10.161E-06 62.592E-04
CURRENT POSITION
     .93287805      .67174087      .57365240      .51241781

BEST MINIMUM =  43.739875E-01 AFTER        340 STEPS (CURRENT STEP SIZE  37.633528E-08)
BEST POSITION .07021668 .02718944 .15127401 .02462351
       RD              GD              AD              JS       RATIO        MINIMUM       RD          GD          AD
ND     11/   217      1/    26    32/     53      0/     44    .3333 43.741330E-01 91.449E-05 10.161E-06 62.592E-04
DIR COS    .6690    -.6516     .3265     .1460
CURRENT POSITION
     .07021693      .02718920      .15127414      .02462356
```

```
BEST MINIMUM =  43.739875E-01 AFTER        360 STEPS (CURRENT STEP SIZE  12.544509E-08)
BEST POSITION .07021668 .02718944 .15127401 .02462351
          RD            GD            AD            JS          RATIO          MINIMUM          RD           GD           AD
ND     11/   233     1/    27    32/     54      0/     46     .3333 43.739907E-01 91.449E-05 10.161E-06 62.592E-04
DIR COS    -.4476     .6745    -.3670    -.4584
CURRENT POSITION
     .07021662       .02718953       .15127397       .02462345

BEST MINIMUM =  43.739422E-01 AFTER        380 STEPS (CURRENT STEP SIZE  37.633528E-08)
BEST POSITION .07021678 .02718959 .15127439 .02462337
          RD            GD            AD            JS          RATIO          MINIMUM          RD           GD           AD
RD     13/   244     1/    28    37/     61      0/     47     .3333 43.743477E-01 91.449E-05 10.161E-06 62.598E-04
DIR COS    -.2868    -.8617    -.1482    -.3915
CURRENT POSITION
     .07021667       .02718927       .15127434       .02462322

BEST MINIMUM =  43.739399E-01 AFTER        400 STEPS (CURRENT STEP SIZE  12.544509E-08)
BEST POSITION .07021678 .02718964 .15127428 .02462333
          RD            GD            AD            JS          RATIO          MINIMUM          RD           GD           AD
RD     14/   259     1/    29    37/     63      0/     49     .3333 43.740018E-01 91.449E-05 10.161E-06 62.598E-04
DIR COS    -.0838    -.0639     .1304     .9858
CURRENT POSITION
     .07021677       .02718963       .15127430       .02462346
IN  401STEPS MIN=,  43.739399E-01  AT
 70.216777E-03  27.189639E-03  15.127428E-02  24.623335E-03


BEST MIN =      4.3739399120E+00
           THETAS
     -1.0162     -2.0000     -2.9608     -3.9468     -5.0000     -6.0758     -7.0358     -7.7994     -8.3817     -8.8306
        A1                 B1                A2                 B2
     1.3241611E+01      3.5778715E+01      5.6105089E+00      3.9611883E+01
```

SA' ' OUTPUT 2

```
   THETAS
-.9018    -1.8586     -2.9074     -4.0373     -5.1706     -6.2043     -7.0801     -7.7933     -8.3666     -8.8287
   A1                 B1                 A2                 B2
1.0000000E+01      4.7000000E+01      7.0000000E+00      3.0000000E+01



STARTIN  MINIMUM=   86.790910E-01  AT
 90.909091E-03  20.833333E-03  12.500000E-02  32.258065E-03

FREQUENCIES=  20 RANDOM   60 GRADIENT   20 AVERAGE   20 JUMP


BEST MINIMUM =  86.790910E-01 AFTER          20 STEPS (CURRENT STEP SIZE  66.666667E-03)
BEST POSITION .09090909 .02083333 .12500000 .03225806
       RD             GD             AD             JS       RATIO          MINIMUM        RD          GD          AD
RD      0/     13      0/      2      0/      0      0/      5    .3333 81.857131E+00  0.          0.          0.
DIR COS   -.2870    -.6356    -.4919    -.5213
CURRENT POSITION
     .07177832      .02153828      .09220926      .00249638

BEST MINIMUM =  86.790910E-01 AFTER          40 STEPS (CURRENT STEP SIZE  22.222222E-03)
BEST POSITION .09090909 .02083333 .12500000 .03225806
       RD             GD             AD             JS       RATIO          MINIMUM        RD          GD          AD
ND      0/     28      0/      3      0/      0      0/      9    .3333 48.813616E+00  0.          0.          0.
DIR COS    .0415    -.0406     .7652    -.6412
CURRENT POSITION
     .09183209      .01993040      .14200354      .01800887

BEST MINIMUM =  72.631988E-01 AFTER          60 STEPS (CURRENT STEP SIZE  74.074074E-04)
BEST POSITION .08678146 .02371421 .11056563 .02558837
       RD             GD             AD             JS       RATIO          MINIMUM        RD          GD          AD
JS      4/     41      0/      4      0/      2      0/     13    .3333 10.891511E+01 29.630E-03  0.          0.
CURRENT POSITION
     .24277721      .88801397      .48692134      .08634623

BEST MINIMUM =  66.209357E-01 AFTER          80 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .08793066 .02944816 .10868127 .02081255
       RD             GD             AD             JS       RATIO          MINIMUM        RD          GD          AD
ND      6/     56      0/      6      0/      4      0/     14    .3333 70.666739E-01 32.099E-03  0.          0.
DIR COS   -.1684     .8906    -.2187    -.3615
CURRENT POSITION
     .08751491      .03164709      .10814118      .01991991
```

```
BEST MINIMUM =  59.416693E-01 AFTER        100 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .08732317 .02845553 .11063729 .02228801
        RD          GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
RD    8/   69     0/    8     0/    7     0/    16    .3333 86.489969E-01 32.099E-03  0.          0.
DIR COS   .5138    .3490   -.2174   -.7530
CURRENT POSITION
     .08859179     .02931716     .11010062     .02042875

BEST MINIMUM =  58.188753E-01 AFTER        120 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .08773438 .02955514 .11013684 .02137757
        RD          GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
JS    8/   80     0/    9     2/   12     0/    19    .3333 89.265894E+00 32.099E-03  0.          16.461E-04
CURRENT POSITION
     .11098545     .47560707     .14748855     .83460505

BEST MINIMUM =  57.711440E-01 AFTER        140 STEPS (CURRENT STEP SIZE  27.434842E-05)
BEST POSITION .08786530 .02958851 .11033400 .02151225
                    GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
JS    8/   92     1/   13     2/   14     0/    21    .3333 11.472591E+01 32.099E-03 27.435E-05 16.461E-04
CURRENT POSITION
     .73041277     .57615165     .96937519     .99838402

BEST MINIMUM =  53.903931E-01 AFTER        160 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .09355669 .03279595 .11835062 .02050000
        RD          GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
RD   16/  102     1/   14     8/   22     0/    22    .3333 53.984375E-01 35.940E-03 27.435E-05 82.305E-04
DIR COS   .4711   -.3063    .7174    .4118
CURRENT POSITION
     .09471978     .03203963     .12012201     .02151686

BEST MINIMUM =  47.234119E-01 AFTER        180 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .09886302 .03655011 .11655221 .01904056
        RD          GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
ND   18/  116     1/   15    10/   26     0/    23    .3333 11.059665E+00 38.409E-03 27.435E-05 13.149E-03
DIR COS   .1947    .4161    .1934   -.8669
CURRENT POSITION
     .09934371     .03757762     .11702962     .01690003

BEST MINIMUM =  42.734977E-01 AFTER        200 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .10687579 .04130790 .11929313 .01795684
        RD          GD          AD          JS        RATIO        MINIMUM        RD          GD          AD
ND   19/  124     1/   16    17/   36     0/    24    .3333 67.919540E-01 39.232E-03 27.435E-05 22.222E-03
DIR COS   .2130    .5015   -.6229   -.5613
CURRENT POSITION
     .10740175     .04254622     .11775511     .01657081
```

```
BEST MINIMUM =  37.565954E-01 AFTER        220 STEPS (CURRENT STEP SIZE  74.074074E-04)
BEST POSITION .13143118 .05135669 .13459999 .01652724
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
RD    21/   133      1/    17    24/    45     0/     25    .3333 14.259578E+00 39.232E-03 27.435E-05 49.383E-03
DIR COS    .4955     .4910   -.5109   -.5023
CURRENT POSITION
     .13510189       .05499345      .13081522      .01280635

BEST MINIMUM =  37.565954E-01 AFTER        240 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .13143118 .05135669 .13459999 .01652724
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
RD    21/   149      1/    18    24/    46     0/     27    .3333 10.261473E+00 39.232E-03 27.435E-05 49.383E-03
DIR COS    .2101     .0637   -.5958   -.7726
CURRENT POSITION
     .13194996       .05151400      .13312898      .01461966

BEST MINIMUM =  30.083638E-01 AFTER        260 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .12851173 .05352609 .14008595 .01669654
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
RD    27/   165      1/    19    24/    48     0/     28    .3333 40.383156E-01 39.232E-03 27.435E-05 49.383E-03
DIR COS   -.1983    -.4419    .8602   -.1595
CURRENT POSITION
     .12802212       .05243495      .14220993      .01630280

BEST MINIMUM =  27.790598E-01 AFTER        280 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .12979089 .05372577 .14186569 .01660363
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
AV    ,     179      1/    20    27/    53     0/     28   0.        ,.790598E-01 40.055E-03 27.435E-05 51.852E-03
DIR COS    .6641     .3599    .6542   -.0392

BEST MINIMUM =  27.384542E-01 AFTER        300 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .13252378 .05520674 .14455772 .01644224
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
ND    29/   191      1/    22    30/    59     0/     28    .3333 34.359853E-01 40.055E-03 27.435E-05 55.967E-03
DIR COS    .1764    -.1316   -.8317   -.5098
CURRENT POSITION
     .13266900       .05509839      .14387321      .01602269

BEST MINIMUM =  25.343478E-01 AFTER        320 STEPS (CURRENT STEP SIZE  24.691358E-04)
BEST POSITION .13247563 .05631144 .14916796 .01639057
       RD            GD           AD           JS      RATIO        MINIMUM       RD        GD        AD
RD    30/   201      1/    23    35/    66     0/     30    .3333 11.840638E+00 40.055E-03 27.435E-05 60.082E-03
DIR COS    .0251    -.2007   -.2086   -.9568
CURRENT POSITION
     .13253770       .05581582      .14865277      .01402801
```

```
BEST MINIMUM =  23.048861E-01 AFTER         340 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .13145847 .05638127 .15181450 .01676372
         RD             GD                AD               JS         RATIO         MINIMUM          RD            GD̄            AD
AV     32/    212      1/     25      39/      73       0/     30    0.       23.048861E-01 40.055E-03 27.435E-05 63.374E-03
DIR COS    -.1433     .1580     .9760      .0432

BEST MINIMUM =  20.068541E-01 AFTER         360 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .12956565 .05618643 .15674354 .01686978
         RD             GD                AD               JS         RATIO         MINIMUM          RD            GD̄            AD
RD     34/    220      1/     27      44/      82       0/     31    0.       20.068541E-01 40.878E-03 27.435E-05 67.490E-03
DIR COS    -.5215    -.7025     .4843      .0041

BEST MINIMUM =  18.073537E-01 AFTER         380 STEPS (CURRENT STEP SIZE  82.304527E-05)
BEST POSITION .12787448 .05522722 .15922343 .01703754
         RD             GD                AD               JS         RATIO         MINIMUM          RD            GD̄            AD
RD     35/    231      1/     28      47/      87       0/     34     .3333 18.643976E-01 41.701E-03 27.435E-05 69.959E-03
DIR COS    -.2736     .1018     .9231      .2505
CURRENT POSITION
      .12764933       .05531096       .15998316       .01724372

BEST MINIMUM =  17.735213E-01 AFTER         400 STEPS (CURRENT STEP SIZE  27.434842E-05)
BEST POSITION .12794508 .05527102 .15931452 .01706620
         RD             GD                AD               JS         RATIO         MINIMUM          RD            GD            AD
RD     36/    246      1/     29      48/      91       0/     34     .3333 21.690260E-01 41.701E-03 27.435E-05 70.233E-03
DIR COS     .7138    -.4245    -.3036     -.4670
CURRENT POSITION
      .12814092       .05515457       .15923123       .01693807
IN  401STEPS MIN=,  17.735213E-01  AT
 12.794508E-02  55.271022E-03  15.931452E-02  17.066201E-03


BEST        .     1.7735212569E+00
             THETAS
        -.9872      -2.0000       -3.0177       -4.0007       -4.9585       -5.9521       -7.0048       -8.0052       -8.8107       -9.4025
          A1                          B1                          A2                          B2
        6.8158534E+00           1.7092663E+01           5.2768919E+00           5.7595347E+01
```

EQUIPMENT: 6600

LANGUAGE: FORTRAN IV

STORAGE:

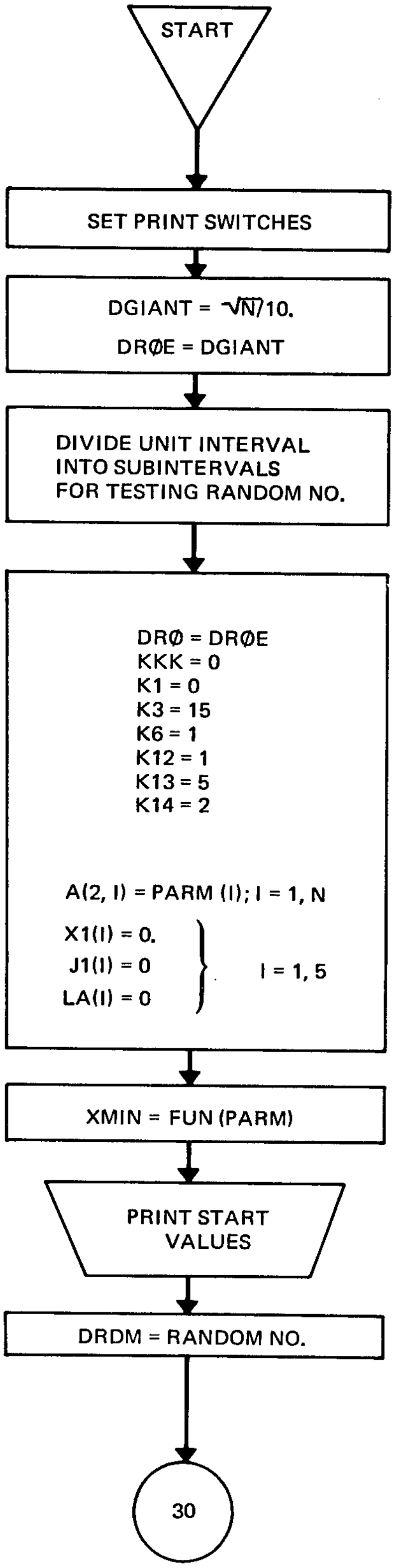
	Octal	Decimal
6600	1647	935

REFERENCES: (1) Pearson, C. E. and W. S. Willman, C Computer Program for Design Optimization, Sperry Rand Research Center, Rpt. No. SRRC-RR-65-48, June, 1965 (See author for copies)

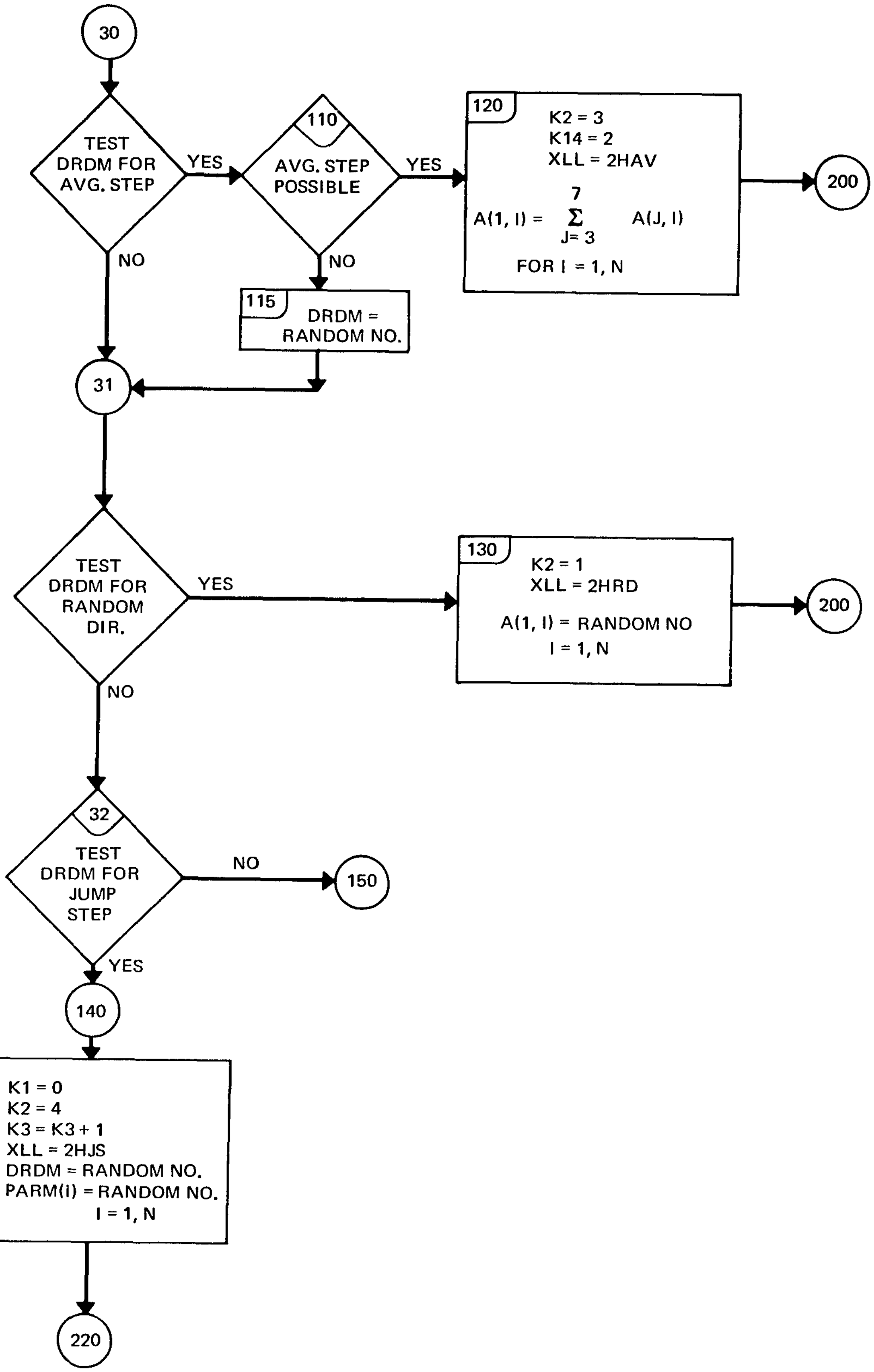
TABLE OF BASIC SYMBOLS

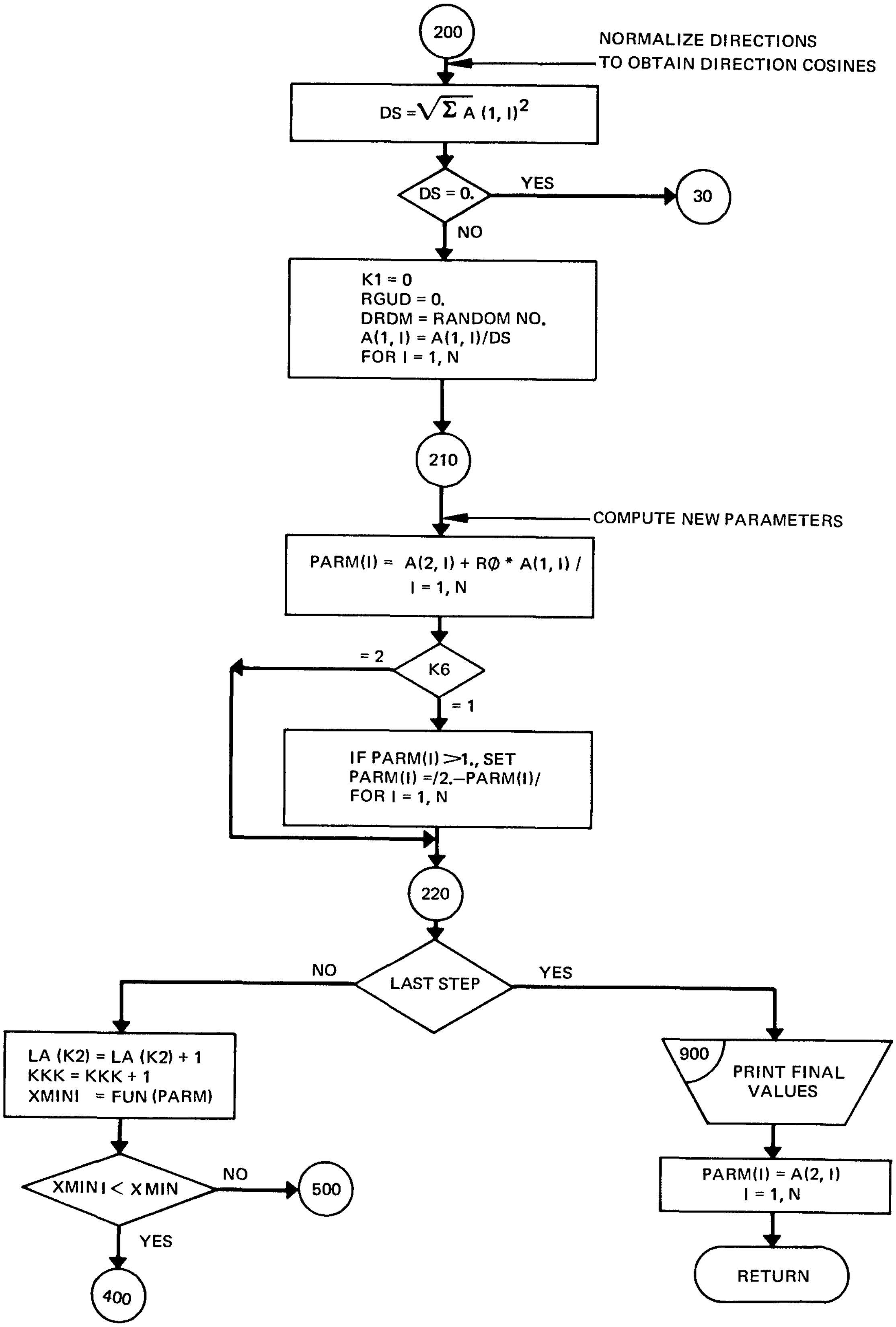
DGIANT	= .1/N
DROE	= STEP SIZE
XMIN	= BEST MINIMUM
DRO	= STEP SIZE
KKK	= NO. OF CURRENT STEPS
K1	= NO. OF SUCCESSFUL STEPS IN THIS DIRECTION
K3	= 15-NO. OF SUCCESSIVE UNSUCCESSFUL STEPS
K6	= SWITCH IF 1 SOME PARAMETER MAY BE AT THE BOUDARY IF 2 THERE ARE K8 STEPS TO THE BOUNDARY
K12	= SWITCH IF 1 GRADIENT IS PERMISSIBLE IF 2 " " NOT PERMISSIBLE
K13	= 5-NO. OF SUCCESSFUL STEPS IN THIS DIRECTION
K14	= SWITCH IF 1 AVERAGE DIRECTION IS PERMISSIBLE IF 2 " " " NOT PERMISSIBLE
K15	= SWITCH IF 1 NORMAL GRADIENT 2 USE GRADIENT AT THE BOUNDARY
K2	= SWITCH IF 1 LAST TRY WAS A RANDOM TRY " 2 " " " " GRADIENT TRY " 3 " " " " AVERAGE " " 4 " " " " JUMP " " 5 " " " " NEGATIVE "
K8	= MINIMUM # OF STEPS TO BOUNDARY
DRDM	= RANDOM #
RGUD	= TOTAL GOOD DISTANCE IN THIS TRY
LA(I)	= NO. OF STEPS IN EACH OF THE FIVE TYPES OF TRIALS
J1(I)	= NO. OF SUCCESSFUL STEPS IN EACH OF THE FIVE TYPES OF TRIALS
X1(I)	= SUCCESSFUL DISTANCE IN EACH OF THE FIVE TYPES OF TRIALS
K10	= LOCATION OF LAST SUCCESSFUL PARAMETERS IN STORAGE
XLL	= HOLERITH TITLE TELLING WHAT TYPE OF TRIAL THE LAST STEP WAS
A(3,I)-A(7,I)	= STORAGE OF SUCCESSFUL DIRECTIONS. DISTANCE IN THAT DIRECTION
A(1,I)-A(2,I)	= WORKING AREAS FOR DIRECTIONS AND PARAMETERS

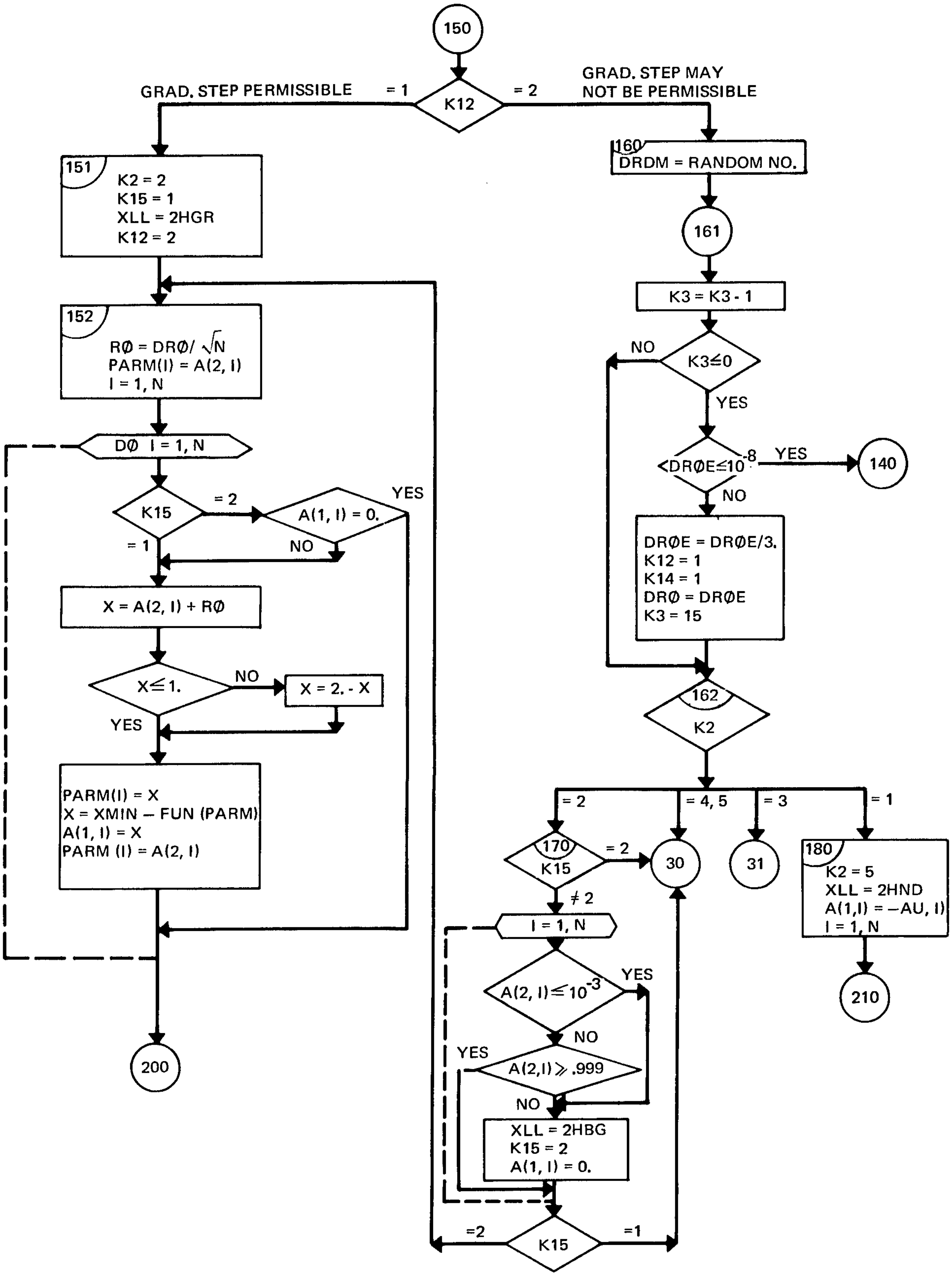
INITIALIZATION

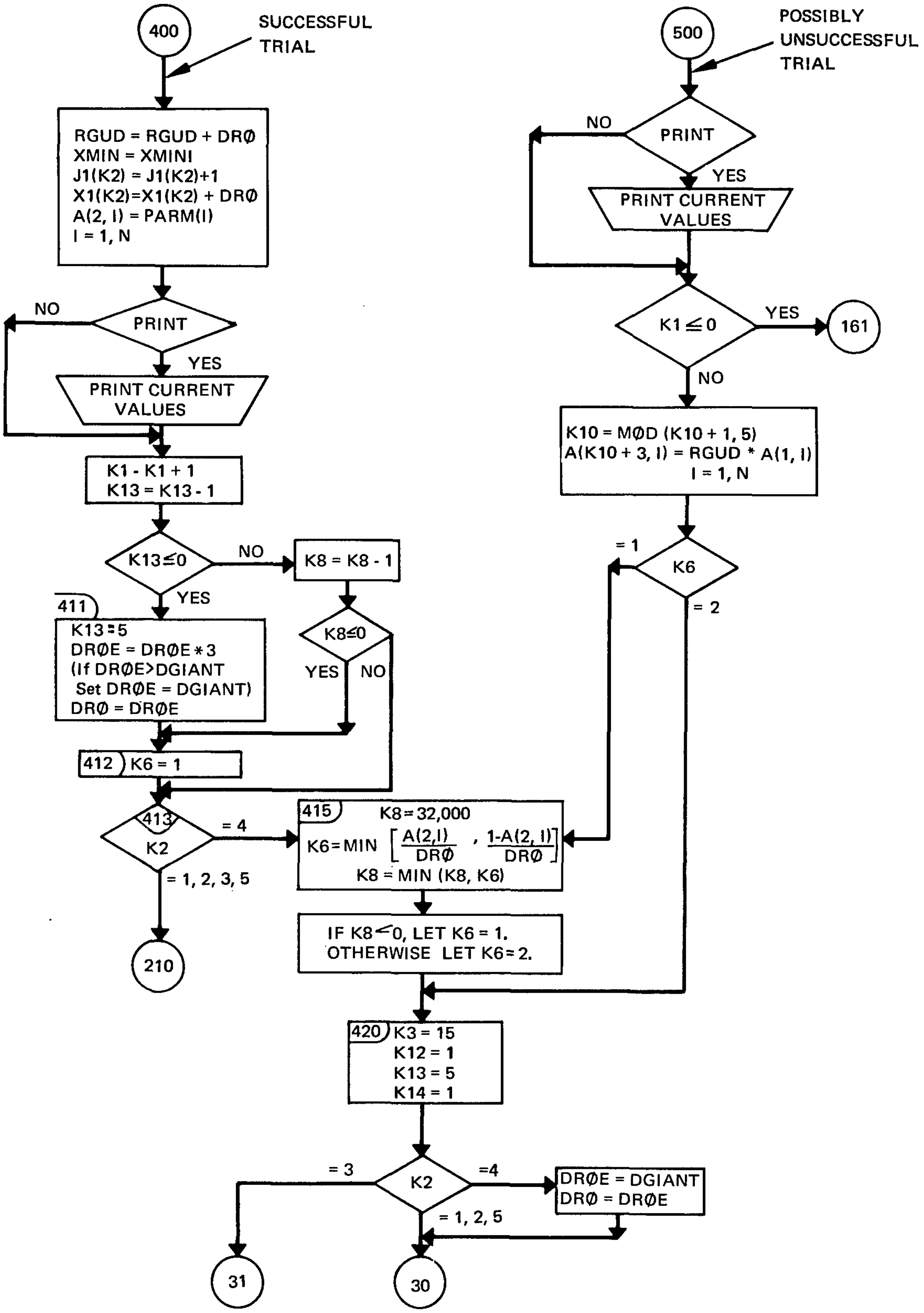


DETERMINE NEXT STEP




200
NORMALIZE DIRECTIONS
TO OBTAIN DIRECTION COSINES
DS = $\sqrt{\Sigma A(1,I)^2}$
DS = 0.
YES
30
NO
K1 = 0
RGUD = 0.
DRDM = RANDOM NO.
A(1, I) = A(1, I)/DS
FOR I = 1, N
210
COMPUTE NEW PARAMETERS
PARM(I) = A(2, I) + RØ * A(1, I) /
I = 1, N
K6
= 2
= 1
IF PARM(I) >1., SET
PARM(I) =/2.–PARM(I)/
FOR I = 1, N
220
LAST STEP
NO
YES
LA (K2) = LA (K2) + 1
KKK = KKK + 1
XMINI = FUN (PARM)
XMINI < XMIN
NO
500
YES
400
900
PRINT FINAL
VALUES
PARM(I) = A(2, I)
I = 1, N
RETURN


150
K12
= 1
GRAD. STEP PERMISSIBLE
= 2
GRAD. STEP MAY NOT BE PERMISSIBLE
151
K2 = 2
K15 = 1
XLL = 2HGR
K12 = 2
152
RØ = DRØ/ √N
PARM(I) = A(2, I)
I = 1, N
DØ I = 1, N
K15
= 2
= 1
A(1, I) = 0.
YES
NO
X = A(2, I) + RØ
X≤1.
NO
X = 2. - X
YES
PARM(I) = X
X = XMIN – FUN (PARM)
A(1, I) = X
PARM (I) = A(2, I)
200
160
DRDM = RANDOM NO.
161
K3 = K3 - 1
K3≤0
NO
YES
<DRØE≤10^-8
YES
140
NO
DRØE = DRØE/3.
K12 = 1
K14 = 1
DRØ = DRØE
K3 = 15
162
K2
= 2
= 4, 5
= 3
= 1
170
K15
= 2
30
31
180
K2 = 5
XLL = 2HND
A(1,I) = –AU, I)
I = 1, N
210
≠ 2
I = 1, N
A(2, I)≤10^-3
YES
NO
A(2,I)≥.999
YES
NO
XLL = 2HBG
K15 = 2
A(1, I) = 0.
K15
=2
=1


400
SUCCESSFUL TRIAL
RGUD = RGUD + DRØ
XMIN = XMINI
J1(K2) = J1(K2)+1
X1(K2)=X1(K2) + DRØ
A(2, I) = PARM(I)
I = 1, N
NO
PRINT
YES
PRINT CURRENT VALUES
K1 - K1 + 1
K13 = K13 - 1
K13≤0
NO
YES
K8 = K8 - 1
411
K13=5
DRØE = DRØE∗3
(If DRØE>DGIANT
Set DRØE = DGIANT)
DRØ = DRØE
K8≤0
YES
NO
412
K6 = 1
413
K2
= 4
= 1, 2, 3, 5
210
415
K8=32,000
K6=MIN [A(2,I)/DRØ , 1-A(2, I)/DRØ]
K8 = MIN (K8, K6)
IF K8<0, LET K6 = 1.
OTHERWISE LET K6=2.
500
POSSIBLY UNSUCCESSFUL TRIAL
NO
PRINT
YES
PRINT CURRENT VALUES
K1≤0
YES
161
NO
K10 = MØD (K10 + 1, 5)
A(K10 + 3, I) = RGUD * A(1, I)
I = 1, N
= 1
K6
= 2
420
K3 = 15
K12 = 1
K13 = 5
K14 = 1
= 3
K2
=4
= 1, 2, 5
DRØE = DGIANT
DRØ = DRØE
31
30

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Appendix X: Subroutine name Index

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A computer program for the evaluation of cockpit configurations using a 23 pin-joint articulated stick-man (BOEMAN-I) is presented. This program utilized an updatable bank of anthropological and environmental data, and simulates the motion of a real pilot performing tasks in a crewstation. The program provides information concerning reach capability, locations and orientations of joints, pilot-cockpit visual interferences, numerical performance indicators on joint displacement and deflection, and mass displacements. The program provides also a statistical validation when comparing real pilot and BOEMAN-I paths of motion. (U)

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Cockpit						
Design						
Environment						
Evaluation						
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Interference						
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Performance						
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